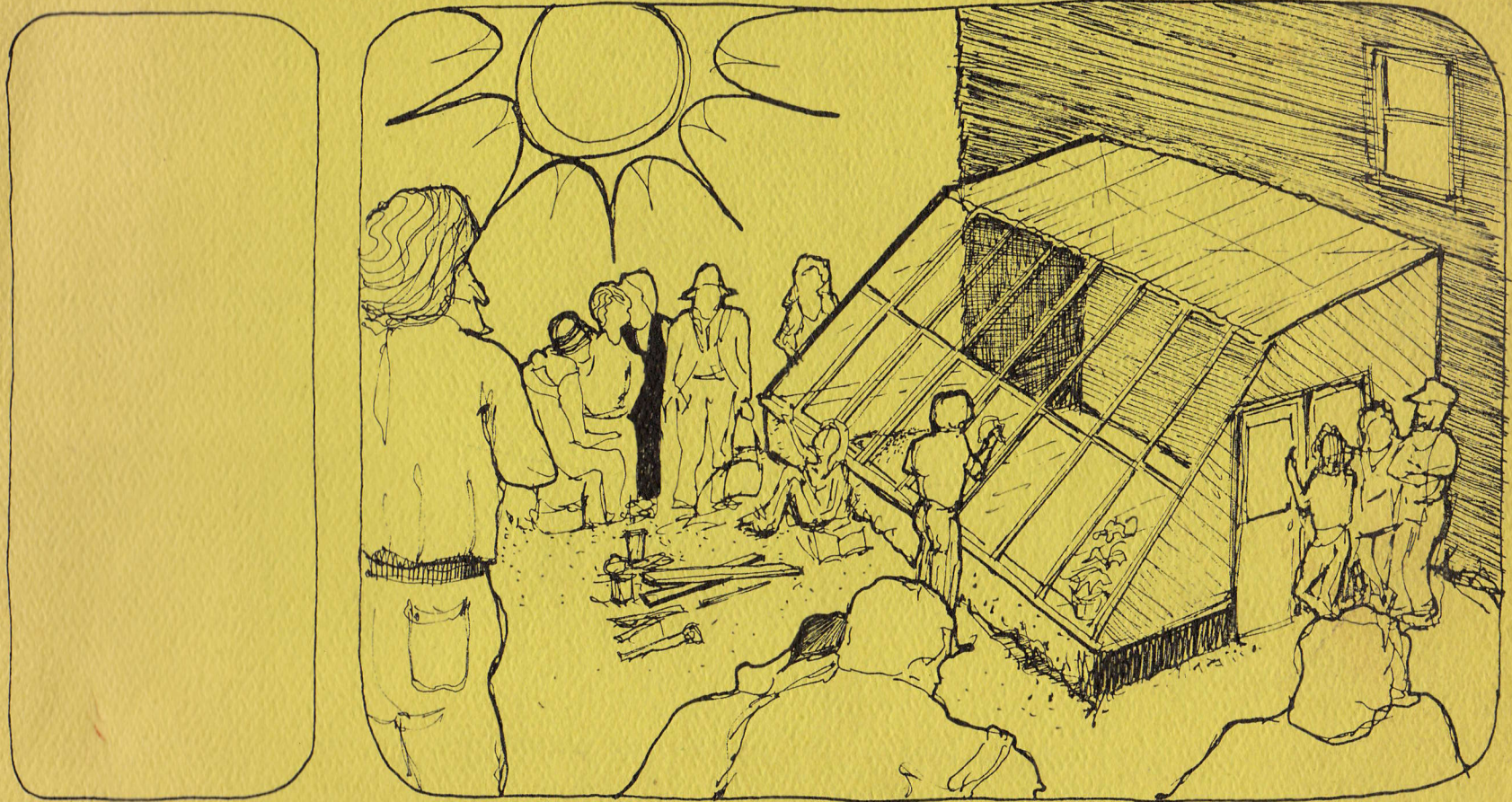


#100

A Solar Greenhouse Guide for the Pacific Northwest



\$6.00

Ecotope Group
2nd edition

A Solar Greenhouse Guide for the Pacific Northwest

TEXT AND
GREENHOUSE DESIGN

Tim Magee with Ecotope Group
"A Windowbox Greenhouse" and
"Freeze Protection And Heat Storage"
by David Baylon
"How To Put On A Workshop"
by Ken Eklund

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Ecotope Group

The insolation data in the Appendix is taken, with Steve Baker's kind permission, from INSOLATION ON SOUTH-FACING TILTED SURFACES: PACIFIC NORTHWEST LOCATIONS.

Drawings C, D, E, and F in the text are from the preliminary draft of a book on solar water heaters by Chris Mattock for B.C. Hydro, and are used with the author's permission.

Susan Gross did the drawings on pages 28, 39, 40, 63, 65

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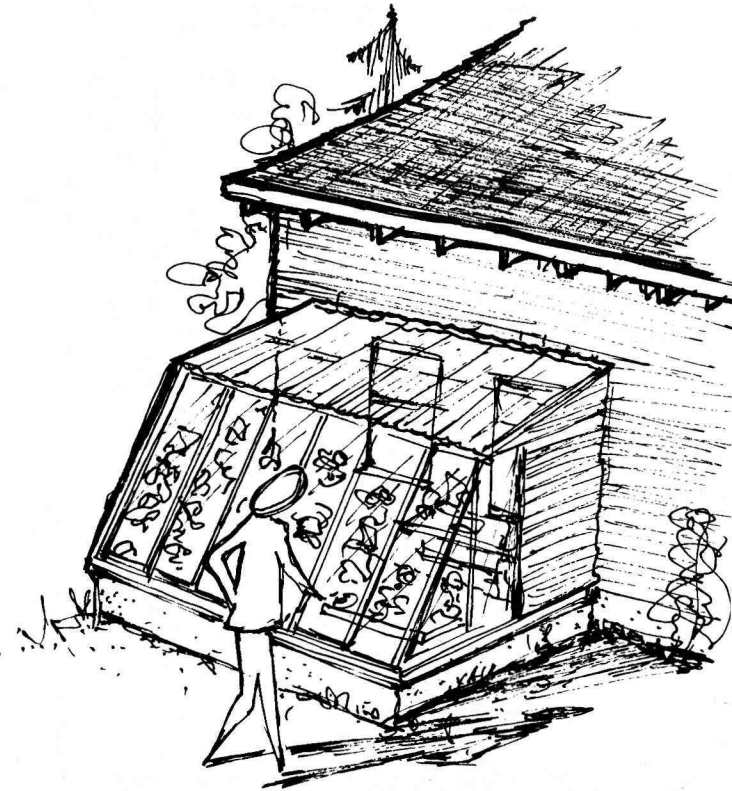
A Solar Greenhouse Guide

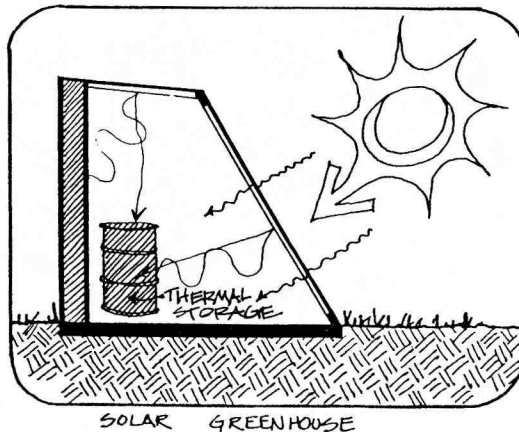
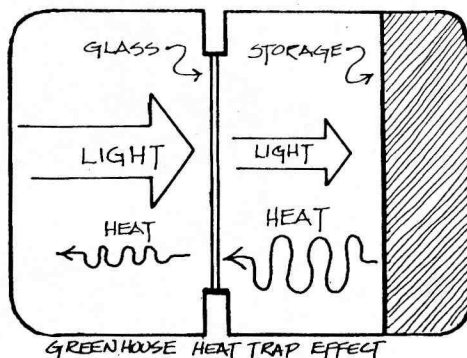
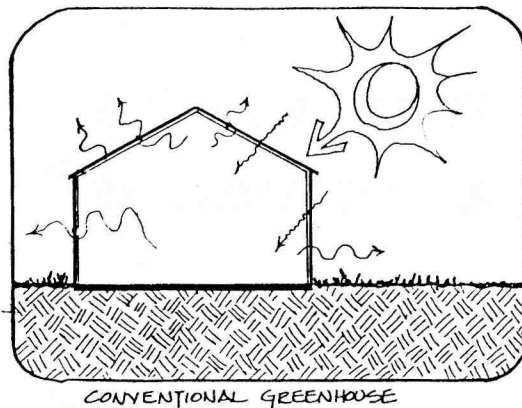
We have in the Northwest an abundance of the most inexpensive hydro-produced electricity in the country. Yet we are faced with the controversial development of thermal power generation to meet our growing energy demands. Predictions of this growing demand are based on the increasing use of electricity for residential heating. Home heating now represents 18% of Seattle's total energy demand (which includes total commercial, industrial and transportation energy usage). Household insulation projects can help lower the growth of our future domestic energy needs. If this is coupled with the use of simple solar heating systems, the future of our domestic energy consumption can be brought below current use levels -- negating the need for increased thermal generating capacity.

The Pacific Northwest exhibits a fortunate balance of weather conditions necessary for the successful operation of solar heating systems. The Seattle area, although cloudy during much of December and January, maintains a relatively mild climate due to the "blanket" effect of the clouds. In this climate, household heating can be inexpensively maintained with passive solar heating backed up with conventional systems using wood, oil, gas or electricity. East of the Cascades, with even greater amounts of sunshine, it is colder in the winter, largely due to the clear evening skies. The abundance of sunshine, if collected and properly used, will supply a substantial percent of heat for an insulated home, even under the conditions of the colder climate.

Combining these diverse climatic conditions with the variety of needs and desires of the Northwest's inhabitants, ECOTOPE GROUP is helping to develop a solar collector that is flexible enough in design to fulfill a diversity of personal and climatic needs. This solar collector -- THE ATTACHED SOLAR GREENHOUSE -- can be designed to be an effective source of heat, and will meet the broad financial, philosophic and aesthetic needs of its users.

Why a Solar Greenhouse?





A solar greenhouse works simply and elegantly as a solar heat collector by accepting the incoming sunlight, which is absorbed and converted to heat within the greenhouse. The glass walls constantly re-radiate part of the heat back into the structure as it tries to escape (the greenhouse effect) and inhibit drafts and breezes from dispersing the collected heat (convective loss).

The idea of collecting heat through the "greenhouse effect" has been in use since Greek and Roman times, but was brought to fruition in the Netherlands during the Sixteenth Century. What we now consider a typical greenhouse is an energy-intensive structure developed through the use of cheap and abundant fossil fuels as heating sources. The shape of the greenhouse was influenced by the convenience provided when rows of them covered large land areas. The original greenhouses designed by the Dutch were in the form of what we contemporarily consider solar greenhouses to be. Their glazed surfaces faced south, with all other surfaces being opaque. These "glasshouses" were attached to large buildings or massive brick and masonry walls, and often used night shutters to resist heat loss.

Three basic distinctions make a *freestanding* solar greenhouse different from a conventional greenhouse.

1. Siting and Orientation

The glazed face of the greenhouse must face south without any obstructions shading the low-angle winter sun. This will allow the structure to collect the maximum amount of available sunlight.

2. Proper Insulation and Air-Tight Construction

All surfaces not receiving direct winter sunlight (northern walls and roof) should be solid and highly insulated. The greenhouse can then "scoop" the sunlight from the southern sky without allowing any of the heat produced to escape through the northern walls.*

*In a conventional greenhouse, the amount of heat lost through the highly conductive northern glazed surfaces is much greater than the amount of heat gained from incoming diffuse northern light.

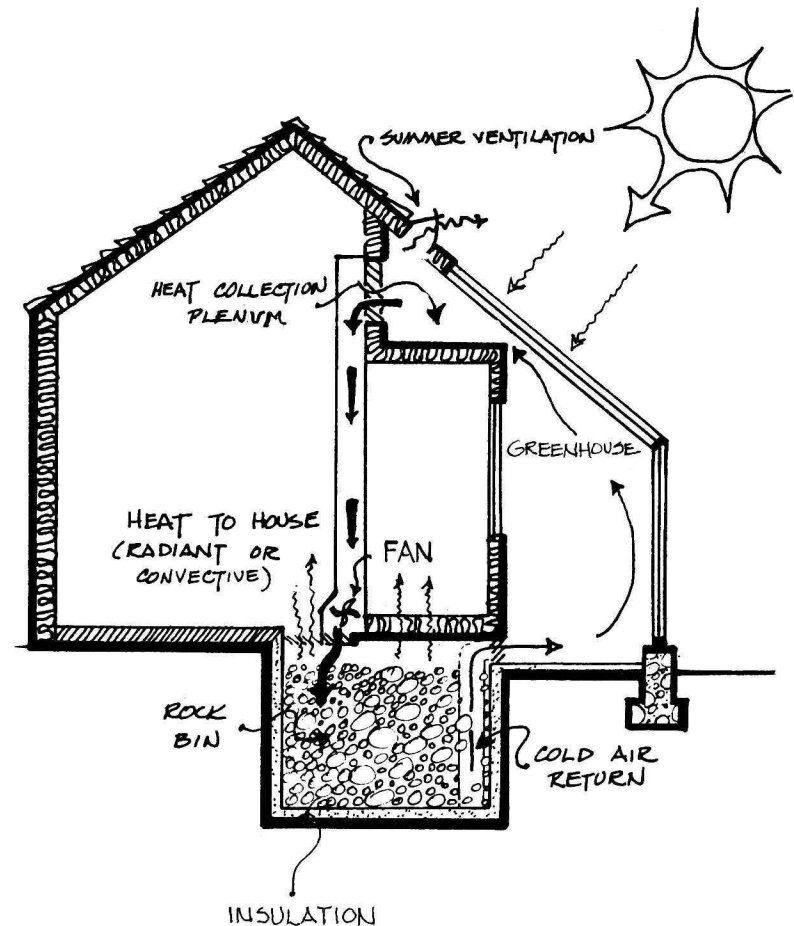
The construction must also be air-tight and weatherstripped to prevent heat loss through drafts.

3. Thermal Storage

All greenhouses are solar heated during sunny periods, and in fact produce an excess of heat which is harmful to plants. A solar greenhouse takes advantage of this excess by warming massive objects within its structure during the day. This heated mass (containers of water, stone, masonry walls) is warmed throughout the day and radiates heat throughout the night, keeping the greenhouse at a comfortable temperature. This heat-storing mass is called THERMAL STORAGE.

A freestanding solar greenhouse takes advantage of this simple "passive" solar principle to collect and store heat for the end benefit of the plants within the structure. The critical temperature here is 32°F. If the greenhouse can be maintained above freezing, the productivity of salad crops and the survival of other plants is assured. Due to the insufficient light levels, short winter days inhibit the production of many food plants. Because of this, the easiest and most productive food plants to grow in a solar greenhouse during the winter are basic salad vegetables. These are not only responsive to low-light winter conditions, but also grow well in a cooler greenhouse. On sunny winter days, a solar greenhouse produces an excess of heat during the day and may be warmer than necessary at night for efficient salad production.

These clues lead us to the possibility of a different use for the excess heat from the greenhouse collector. Attached to the southern side of a home, its excess heat can be vented into the home. The greenhouse heat is available for the house during daylight hours and the house loses heat at night through the windows and walls into the greenhouse. In colder climates such as the Pacific Northwest, the heat lost from the house is not usually sufficient to maintain the greenhouse above freezing during the severest parts of winter. Thermal storage should then be added to keep the greenhouse warm. In this case, however, more is not better. Too much thermal mass will absorb heat in the day and "rob" the house. Care must be taken to insure that the greenhouse keeps only the heat required to maintain a comfortable growing temperature for the winter growing activities.



An *attached* solar greenhouse must have these qualities:

Initial Home Conservation Measures

A solar greenhouse will not function effectively on a leaky, poorly insulated house. The greenhouse should be thought of as part of a conservation process for the home. This includes:

- full insulation
- weatherstripping } for poorly fitting windows and doors
- caulking
- insulated windows or stormwindows or
- possibly insulating shutters or curtains

Siting and Orientation

The glazed face of the greenhouse must face south with no obstructions shading it from the low-angle winter sun. This will allow the structure to collect the maximum amount of winter sunlight.

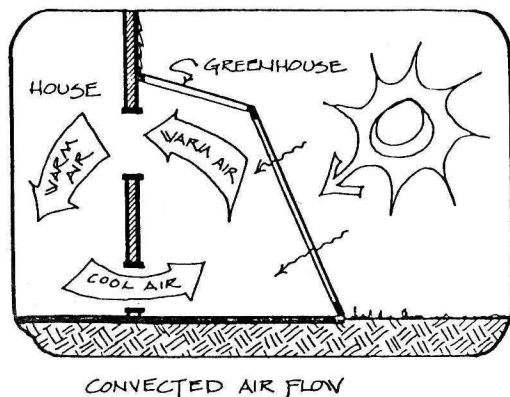
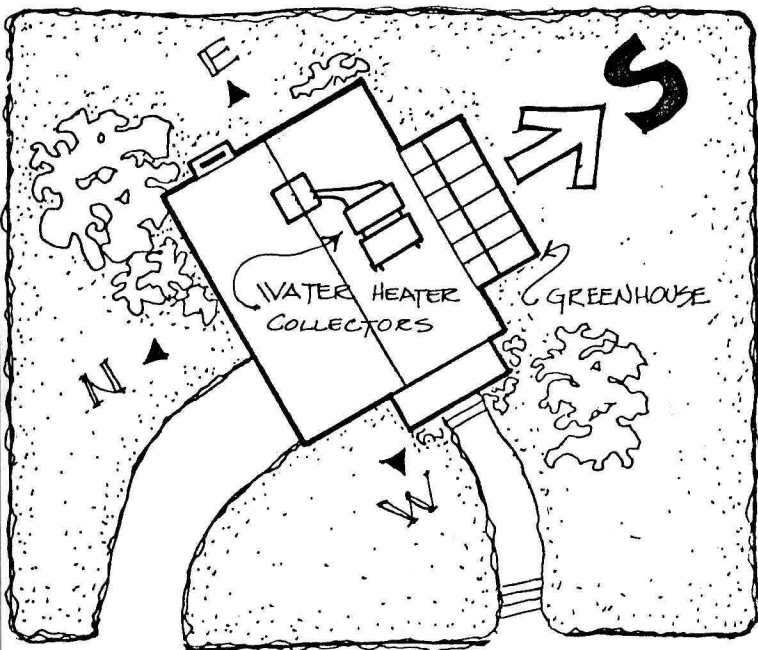
Proper Insulation and Air-Tight Greenhouse Construction

All or part of the end walls should be well-insulated to resist heat loss. The construction must also be caulked and weatherstripped to prevent heat loss through drafts.

Connection to the House

The greenhouse needs to be attached so that it covers an opening into the house. During the day, the collector will share its excess heat with the house as warm air rises in through the opening. At night, the collector should be sealed off so the house may retain the collected heat as long as possible. This is most simply accomplished with a "lean-to"-type greenhouse added on over an existing door or window.

An attached solar greenhouse takes advantage of simple passive solar technologies to collect heat for the end benefit of the house and its inhabitants, without a loss in efficient growing conditions. The greenhouse performs the service of being alternately a collector and a conserver of home heat.

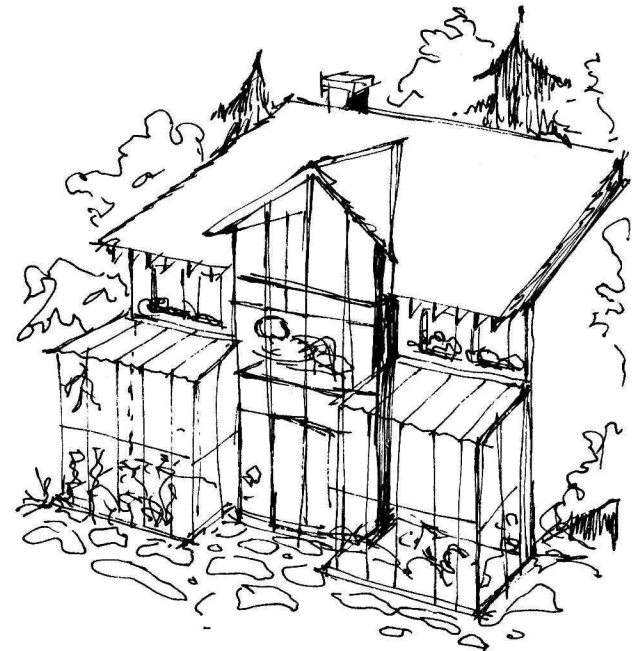


The solar collector greenhouse may be designed to fit in with any architectural style or personal taste. It may be used as an atrium, covered patio, breakfast nook, or as a living room. But the use of a collector as a *greenhouse* will be of value on many levels. A \$200 direct savings on vegetables may be had in a year out of a solar greenhouse if intensively managed. One may also produce a myriad of vegetable starts and annuals for garden use. A great contribution of the solar greenhouse is the potential for local food production. This local production in a working relationship with our regional farmlands can mean a reduction in our national energy and food demands.

If you don't have room or for any other reason cannot put a greenhouse on the side of your home, there are other options for increasing the solar heat contribution to your living space. One way is to build an attached windowbox greenhouse that will increase your solar aperture and provide a plant growing area. See the chapter titled A WINDOWBOX GREENHOUSE for construction details.

We are caught in a web -- our dwindling fossil fuels are raising our costs of living. The word *conservation* to many means giving up some pleasurable aspects of their lives. By designing, constructing and living with an attached solar greenhouse, you will be enjoying a transitional tool which will help you to lead a richer life while maintaining a lower energy profile.

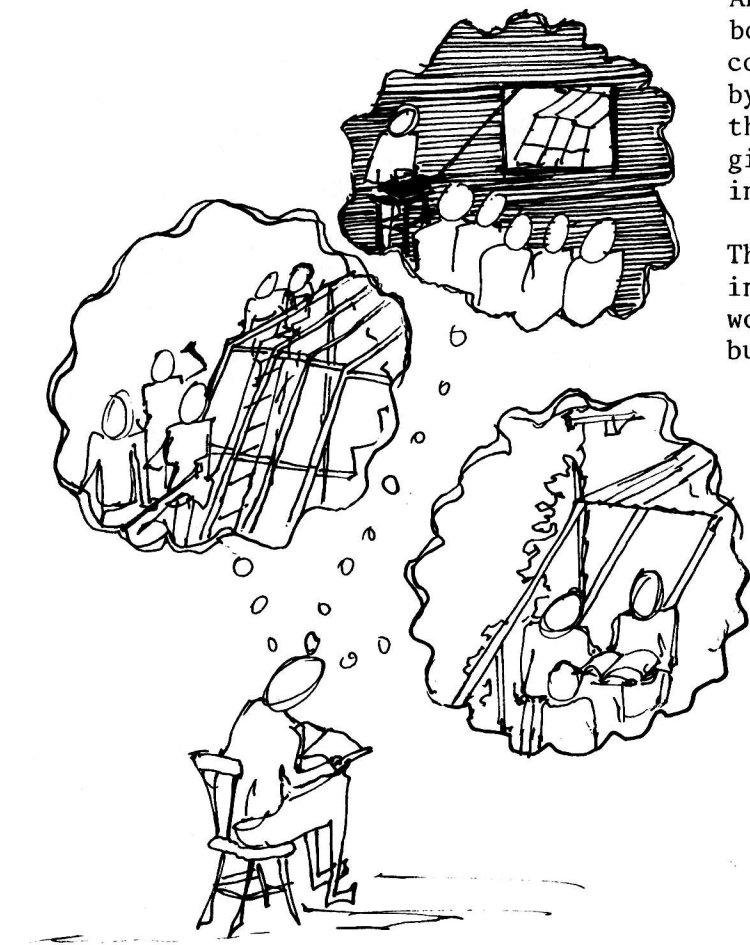
We need to implement energy systems which provide the same quality energy as needed for their intended use. *Capturing the sun in a greenhouse at 100°F in order to heat a home at 68° is energetically efficient and appropriate.* The quality of heat collected from the sun in a passive greenhouse or windowbox is well matched to an end-use of home heating.



ECOTOPE's solar greenhouse workshops are designed specifically for the Pacific Northwest. As a workshop participant you will get theory, design knowledge and informational access, gaining a very real understanding of solar heating so that you may design and build your own system. Working with others on the actual construction of a greenhouse, you will gain the confidence and skills necessary to begin building one of your own.

An evening seminar, along with this GUIDE and several reference books, will cover the ground rules of theory and design. In the two construction days of the workshop, a complete system is built by the workshop participants. Constant review and discussion allows the workers to gain a thorough understanding of the project, and gives them the chance to serve as both teachers and learners of the individual skills.

This guide follows the workshop process and supplies more in-depth information for your specific needs. With the experience from the workshop and these guidelines, you will have the resources to build your own -- or even lead a workshop with friends.



Will It Work In the Northwest?

People in the Northwest are concerned about the *feasibility* of solar heating in their area. Another concern is for the initial expense of a solar system and the potential savings returned over conventional heating costs. This section of the guide will detail the costs and payback analysis of a basic design and will show the effects that a solar remodel can have on an average house in Seattle. The benefits are shown by placing the same house in four other representative areas in the Northwest. By comparing this information to your house and location, a quick idea of the performance of a solar remodel on your home can be made.

Our sample house is a small-to-average three-bedroom family home with a full basement, main floor and converted attic. The heated floor area is 1320 ft² and it has an annual fuel consumption of 770 gallons of oil (\$358/year @ 46½¢/gallon), maintaining a 65°F daytime and a 55° nighttime temperature. The only insulation currently in place is 4" of rockwool in the ceiling joists.

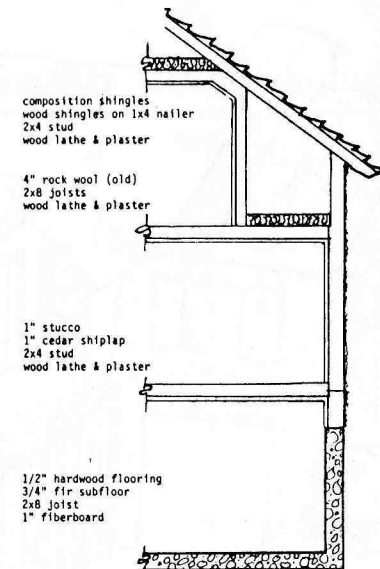
The first concern when determining the feasibility of a solar remodel is the extent to which the house is insulated and what improvements can be made. *Any solar heating system will not perform efficiently in a drafty, poorly insulated house.*

To determine the cost benefits of a solar remodel on the sample house, an extensive heat loss analysis was performed on its present condition. Then, conservation measures were detailed:

- complete insulation
- weatherstripping and caulking
- placement of storm windows

A second analysis was performed and a comparison made in the cost-benefit of reduced heat loss through conservation. A small solar greenhouse was designed and a solar survey showed the amount of available sunlight. The solar gain was subtracted (after multiplication by an efficiency factor) from the conserving heat loss figure to arrive at the final heating needs for the season after a full solar remodel.

SOUTH ELEVATION:



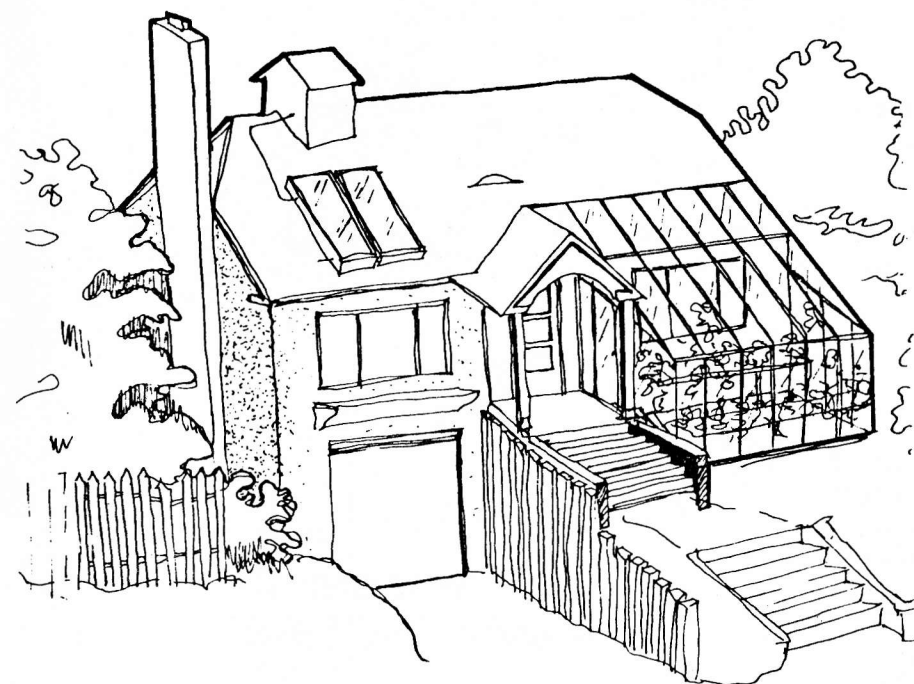
CROSS SECTION

Regional Feasibility

The conservation modifications made in the house brought its insulating levels up to:

- R-15 to R-20 for the walls
- R-30 to R-40 for the ceilings
- R-19 for the floor
- Double-glazed windows (storm windows)
- one-third to one-half reduction in infiltration losses through weatherstripping and caulking

The greenhouse collector which was designed has 234 ft² of collecting surface. It uses a simple fan and rockbin storage system for increased collection efficiency and to expand the time for use of available heat. The costs for the system, assuming that the owners would do some of the less technical work, were:



ESTIMATED COSTS:

SOLAR

greenhouse @ \$7.00/sq.ft. glazing	\$1638
controls & fan	100
storage bin	200
rock	50
ducts	50
installation	500
	2538

CONSERVATION insulation

roof @ 30¢ sq.ft.	220
attic walls @ 25¢ sq.ft.	172
exterior walls @ 50¢ sq.ft.	388
floors @ 35¢/sq.ft.	257
storm windows	140
weatherstrip & caulk	50
vestibule entry	300
	1527

Contingencies	400
Design	400

TOTAL \$4865

PAYBACK ESTIMATES:

	low	high
Total System	12.2	16.5 years
Conservation Only	7.5	9.1
Solar Only	20.5	32.7

The figures in this chart are for a contractor-installed greenhouse. For a do-it-yourself greenhouse, the cost should be less than \$5 per square foot of glazing if you buy all new materials.

BTU/ft²/hr-°F

The amount of heat, measured in BTU's, lost through one square foot of a surface area (of given thermal conductivity) for every one degree Fahrenheit difference between inside and outside temperatures in one hour.

GROSS HEAT LOSS II: This is calculated the same as for the uninsulated house, but figured for the new insulating qualities of the conservation house.

NET HEAT LOSS II: Heat loss is figured again, subtracting internal and solar gains, for the new conserving house. By performing the conservation measures, the heating season for the house was cut down from nine months to six months. *No heat is added: only its loss is restricted.* The cost for heat is now \$130/year, a savings of \$228/year.

SOLAR GAIN WITH COLLECTOR: This is the amount of heat in BTU's contributed to the house by the new solar greenhouse.

NET HEAT LOSS WITH COLLECTOR: The heat demand of the conserving house after the solar greenhouse is added. The heating season is reduced another two months.

The total heating bill for the house is now \$60/year, a savings of \$298/year.

The figures show that by insulating our sample house, the cost of heating (78.6 MBTU) is reduced by two-thirds! Of the one-third left (28 MBTU), over half (15 MBTU) of the heat is supplied by the greenhouse collector, and the remainder (13 MBTU) can be supplied by \$60 worth of oil or one cord of wood (17 MBTU) burned at 75% efficiency in a good wood stove

It is important to notice that, although the greenhouse is supplying one-half of the home's heat, doubling the size of the greenhouse will not fulfill the entire heating needs of the house. The solar gain in December and January is too low for practical 100% solar heating under Washington's cloud cover. Increasing the size of the collector will greatly enhance its heating capability for the rest of the heating season and will increase the daily heating comfort level. We can economically justify 75% solar heating of a home, but there will be a point of diminishing returns. Remember that 95% solar heated homes are designed with full conservation and good orientation at the outset; in this case we are dealing with homes not built to full conservation standards.

The payback periods on the \$4865 initial investment for the remodel were estimated on a 15-year housing improvement loan at 9% interest. Inflation was based at 6% per year and the escalation of fuel costs was estimated to be 15% per year. The pay-back period shown for this remodel (12.2 years) is less than the life of the 15-year loan.

The effectiveness of solar heating in a solar/conservation remodel is shown by the comparison between pay-back estimates of a "conservation only" remodel and a "solar only" model. The conservation will pay for itself in 7.5 years, while simply adding a greenhouse without providing for conservation will mean a 20 year pay-back of investment costs over heat savings.

The combination of conservation with solar in the remodel, with a 12.2-year pay-back, will save 83% of the energy now used to heat this house. Such remodels of existing houses on a nationwide scale could mean a substantial amount of energy saved!

The chart in the right column shows the potential heat savings for a similar house as a solar remodel done in four other locations:

- Coastal (Astoria)
- Inland Oregon (Corvallis)
- SE Washington desert (Prosser)
- NE Washington (Spokane)

There are so many micro-climates in the Northwest that some imagination may be necessary to make comparisons with your location, but these are a good cross-section of regional variations. Local climatological data may be had from your local weather station, college meteorological or U.S./state Forestry department if you wish to determine more exact figures for your specific locale.

Potential Heat Savings for a Solar Remodel at Pacific Northwest Locations

<i>Based on BTU's needed per year at \$4.60/MBTU</i>	<i>cost of heating fuel</i>			<i>total savings</i>
	<i>uninsulated</i>	<i>conserved house</i>	<i>with greenhouse collector</i>	
Seattle	\$358	\$130	\$60	\$298
Astoria	435	145	57	378
Corvallis	391	146	76	315
Prosser	445	172	75	370
Spokane	574	231	123	451

Monthly Heat Demand Charts are in the appendix.

Resistance Values of Various Building Materials, Insulations, and Air Films

BUILDING MATERIALS

Aluminum (1")	R-0.81
wood bevel siding	R-0.81
wood siding shingles	R-0.87
asbestos- cement shingles	R-0.03
stucco (per inch)	R-0.20
or common brick	
½" insulated board sheathing	R-1.32
regular density	
½" plywood	R-0.21
½" plywood	R-0.62
softwood (per inch)	R-1.25
concrete blocks ordinary 8"	R-1.11
cinder aggregate, 8" thick	R-1.72
4" thick	R-1.11
granite masonry	R-0.08 to .04
face brick (per inch)	R-0.11
sand & gravel concrete	
per inch	R-0.08
8" thick	R-0.64
½" gypsumboard	R-0.45
½" aggregate gypsum plaster	R-0.32
lightweight	
25/32" hardwood finish	R-0.68
flooring	
asphalt, linoleum, vinyl, or	R-0.05
rubber floor tile	
carpet and fibrous pad	R-2.08
carpet and foam pad	R-1.23
asphalt roof shingles	R-0.44
wood roof shingles	R-0.94

AIR FILMS

(surface 70°F)	non-reflective	reflective
Still air	(R= 1/C)	
--horizontal surface	R-0.61	R-1.32
heat flow up		
--horizontal surface	R-0.92	R-4.55
heat flow down		
--vertical surface	R-0.68	R-1.70
heat flow horizontal	R-0.68	R-1.70
air space ¾" @ 50°F	R-0.96	R-2.80
Moving air		
--any position		
7½ mph wind	R-0.25	
15 mph wind	R-0.17	
--air space ¾" @ 50°F		
vertical surface	R-0.96	R-2.80
(heat flow horizontal)		

INSULATORS

listed thickness R(=1/C)	
Zonolite	R-2.08
macerated paper (Cellulose)	R-3.57
mineral wool	R-3.33
bead--shredded polystyrene	R-3.3
sawdust and shavings	R-2.2
kapok	R-4.0
mineral wool (fiberglass)	R-3.12
cork	R-3.7
glass fiber	R-4.00
expanded polystyrene	R-3.57
extruded polystyrene	R-5.00
Freon-expanded urethane	R-5.88

WALLS

(depth below grade)	
0-1'	R-2.4
1'-2'	R-4.6
2'-3'	R-6.3
3'-4'	R-8.3
4'-5'	R-10.4
5'-6'	R-12.7
6'-7'	R-14.5

FLOORS

(foundation depth below grade)	average R house width				
	20'	24'	28'	32'	
5'	31	34	38	43	
6'	33	37	40	45	
7'	34	38	43	48	

Average R value over all of basement floor. R near edges in lower -- approaches R for basement wall at bottom edge.

For U values of GLASS, see page 16.

This information was compiled from *Insulation Manual: Homes/Apartments* prepared by the NAHB Research Foundation, and from notes compiled by Ken Cooper of Solar Applications and Research, Ltd., Vancouver, BC

Additional resistance values for other materials can be found in the *ASHRAE Handbook of Fundamentals*.

Features of Buildings with Different Infiltration Rates

building component	1 air change/hour	2 air changes/hour	3 air changes/hour
building with cellar	caulked sills, no cracks, sealed windows, no entrance leaks	some foundation cracks, no window weatherstripping, grade entrance not tight	stone foundation, many leaky cracks, poor seal around grade entrance
or-			
with crawl space on posts	plywood floor, no leaks around trapdoor, water, sewer and electrical openings	tongue-&-groove floor, reasonable fit around trapdoor, pipes, etc.	board floor, loose fit around pipes, etc.
windows	good fitting storm windows	no storm windows, but regular windows fit well	no storm windows and loose fitting regular windows
doors	storm doors that fit well	loose storm doors and poorly fit inside door	no storm doors and loose fit on inside door
walls	building paper under siding, caulked windows and doors	poor caulking, building needs paint	no building paper, cracks around doors and window frames

Will It Work for Me?

A well-insulated home will save you money with or without solar heating -- and it will also take a load off the nation's total energy demand. "Tightening" up your house is an essential starting point for a solar remodel. It may take from two to four hours to assess your home and to see possible conservation measures and savings available, but it will give you the strong base necessary for future solar design considerations.

Heat is lost in your home to air infiltration, and because heat is transmitted out through floors, ceilings, walls, windows, and doors. To find out how much you're losing, you need to measure the surface area of your home and its different parts and figure its volume. These measurements need only include the portions of your home that you heat (don't include an unheated basement you aren't planning to remodel). You can then determine the U VALUE of the different parts of your home and find the TOTAL MONTHLY HEAT LOSS for your house.

The U value of a material is its heat loss in BTU's PER HOUR PER SQUARE FOOT IN DEGREES FAHRENHEIT ($\text{BTU/hr/ft}^2\text{-}^\circ\text{F}$). By multiplying the U value of each different part of your house, you can determine the house's total heat loss in $\text{BTU's/hr-}^\circ\text{F}$.

A Heat Loss Analysis

With a friend, a tape measure and some graph paper, measure and lay out each exterior wall of your house. Include door and window measurements in the drawings. Also measure and lay out the area of the ceiling of your top floor. In converted attics, the sloping walls should be considered ceilings.

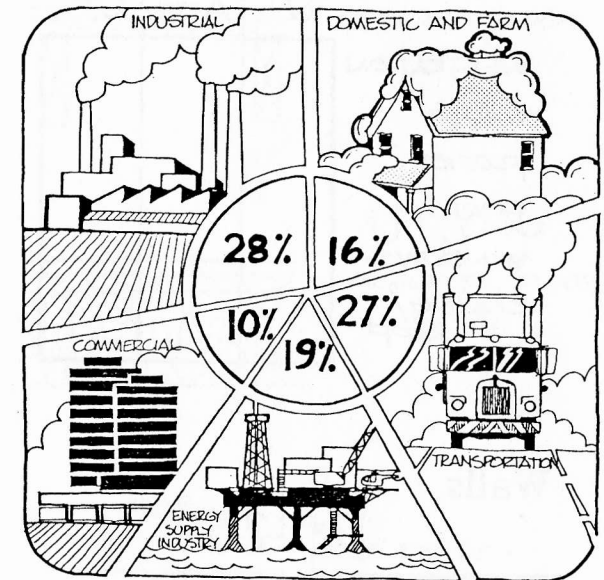
Infiltration

Determine the volume of your house by multiplying its ground floor area by the total height of the living areas. Decide from the *Air Exchange Chart* how many times an hour you lose this volume of warm air and therefore have to reheat it.

Example:

$$1000 \text{ ft}^2 \cdot 8' = 8000 \text{ ft}^3 \cdot 2 \text{ changes/hr} = 16,000 \text{ ft}^3/\text{hr} \\ \text{floor area/ ceiling}$$

Energy Use



R-Value

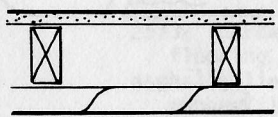
A material's "resistance" value is the inverse of its U value. R-11 insulation has a U value of $1/11$. To determine the U value of a composite section, add up the total of the R values and determine the inverse value. The U values may not be added together to determine a total.

Specific Feasibility

Heat Loss Chart

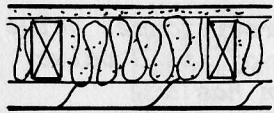
	U	Area	UA
INFILTRATION			
WALLS			
FLOORS			
DOORS			
WINDOWS			
CEILING/ ROOF			

Walls



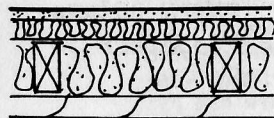
$$U = .25$$

PLASTER
AIR SPACE
SIDING



$$U = .08$$

PLASTER
R-11 INSULATION
SIDING



$$U = .055$$

PLASTER
2.5" STYROFOAM
R-11 INSULATION
SIDING

By multiplying this by the heat capacity of air (.018 BTU/ft³ -°F), you will find the total infiltration heat loss for your house in BTU/hr-°F (equivalent to the UA values in the *Heat Loss Chart*).

Example:

$$16,000 \text{ ft}^3/\text{hr} \cdot .018 \text{ BTU}/\text{ft}^3/\text{hr} = 288 \text{ BTU}/\text{hr}-^\circ\text{F}$$

Enter this figure in the UA column of your *Heat Loss Chart*

Walls

Determine the total area of your walls *minus* the windows and doors. Draw a cross section of your walls showing the materials that they are made of. Examples of materials with their U values are shown here. If you need a more exact figure, refer to the chart on page 12 for the U and R values of different materials. Multiply the wall area by its appropriate U value.

Example:

$$1200 \text{ ft}^2 \cdot .25 \text{ BTU}/\text{hr}/\text{ft}^2-^\circ\text{F} = 300 \text{ BTU}/\text{hr}-^\circ\text{F}$$

Enter this figure in the UA column of your chart.

Floors

Although the floor area is multiplied by the U value of the materials like the walls, some adjustments must be made:

1. Uninsulated floor over a crawlspace or basement loses heat at a lower rate than a wall and has an adjustment factor of .4.

Example:

$$1000 \text{ ft}^2 \cdot .4 \text{ BTU}/\text{ft}^2/\text{hr}-^\circ\text{F} \cdot .4 \text{ adjustment factor} = 160 \text{ BTU}/\text{hr}-^\circ\text{F} \text{ floor area}$$

2. An insulated floor over a basement or crawlspace also loses heat at a lower rate than a wall and has an adjustment factor of .75.

Example:

$$1000 \text{ ft}^2 \cdot .046 \text{ BTU}/\text{ft}^2/\text{hr}-^\circ\text{F} \cdot .75 \text{ adjustment} = 34.5 \text{ BTU}/\text{hr}-^\circ\text{F}$$

3. For a slab floor such as your basement, the simplest calculation to make is to multiply the number of perimeter feet of your house by .81 BTU/hr-°F/linear feet to see how much heat is lost

out of the floor through the ground.

Example:

$$220 \text{ ft} \cdot .81 \text{ BTU/hr-}^\circ\text{F/ft} = 178 \text{ BTU/hr-}^\circ\text{F} \text{ perimeter}$$

4. If you insulate your foundation to the depth of the footing with 2" of structural styrofoam, multiply the number of perimeter feet of your house by .23 BTU/hr- $^\circ$ F/linear feet.

Example:

$$220 \text{ ft} \cdot .23 \text{ BTU/hr-}^\circ\text{F/linear feet} = 50.6 \text{ BTU/hr-}^\circ\text{F} \text{ linear}$$

Determine which floor heating situation is applicable to you and enter the figure from your computations into the UA column of the *Heat Loss Chart*.

Doors

A typical solid core exterior door will have a U value of .2.

Example:

$$3 \text{ doors @ } 6'8'' \times 2'6'' = 50 \text{ ft}^2 \cdot .2 = 10 \text{ BTU/hr-}^\circ\text{F}$$

Enter these numbers into the chart.

Windows

The U value of your windows will vary according to the number of dead air spaces that are formed by storm windows or double glazing. Multiply the number of square feet of windows in your home by their appropriate U value and enter the figure in the chart. (The "U Value Chart" is on page 16.)

Example:

$$140 \text{ ft}^2 \cdot 1.13 \text{ BTU/hr/ft}^2\text{-}^\circ\text{F} = 158 \text{ BTU/hr-}^\circ\text{F}$$

Ceilings

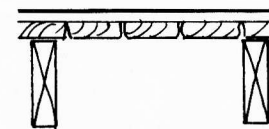
Perform the heat loss analysis of the ceiling in the same manner as the walls, but adjust it with a multiplication factor of 1.2 as they lose heat at a faster rate than walls. Enter your total.

Example:

$$1000 \text{ ft}^2 \cdot .3 \text{ BTU/ft}^2\text{/hr-}^\circ\text{F} \cdot 1.2 \text{ adjustment} = 360 \text{ BTU/hr-}^\circ\text{F}$$

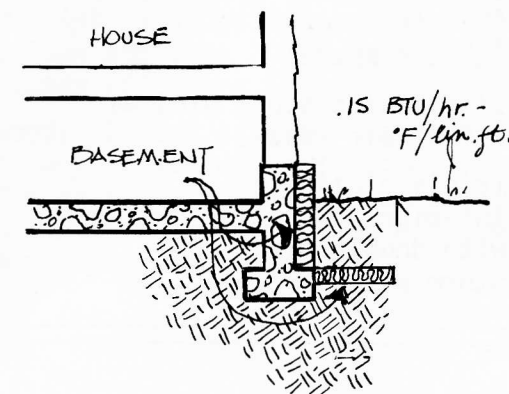
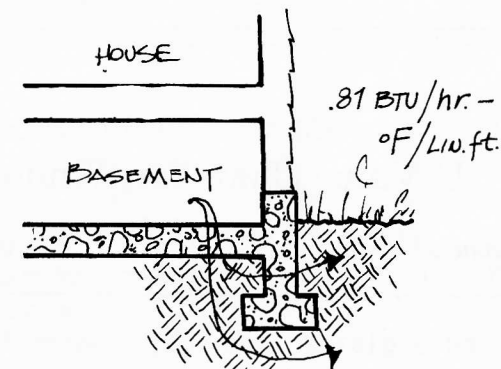
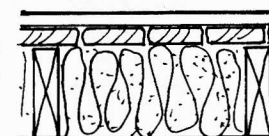
$$U = .4$$

TYPICAL FLOOR

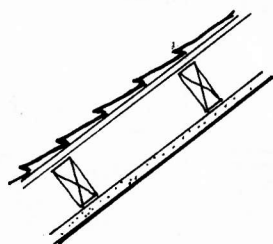


$$U = .046$$

INSULATED FLOOR
R. 19



Ceiling



$$U = .3$$

SHINGLES
SHEATHING
DEAD AIR SPACE
PLASTER

U Value Chart for Windows

<i>window type</i>	<i>U value</i>
single glazed	1.13
double glazed	
($\frac{1}{4}$ " air space)	.65
($\frac{1}{2}$ " air space)	.58
single with storm windows	.56
(1"-4" air space)	
triple glazing or	.38
interior insulating shutters	
with double glass or	
storm windows	

Sample Heat Loss Chart

	<i>U</i>	<i>Area</i>	<i>UA</i>
<i>Infiltration</i>	.018 • 2 changes/hr	8000 ft ³	288
<i>Walls</i>	.25	1200 ft ²	300
<i>Floor</i>	.4	1000 ft ²	160
<i>Doors</i>	.2	50 ft ²	10
<i>Windows</i>	1.13	140 ft ²	158
<i>Ceiling</i>	.3	1000 ft ²	360

Total:

1276 BTU/hr-°F
x 24 hours

= 30,624 BTU/day-°F

This final figure when multiplied by the degree days in the *Monthly Heat Demand Chart* will give you the heat loss for your home on a monthly basis, or for the entire heating season if you are maintaining 65°F. The appropriate degree days for regions other than Seattle may be found in the appendix.

Heat Gain

Internal heat gain and solar heat gain in the house must be subtracted from the gross heat loss to give an accurate total figure.

People and appliances contribute some home heating. A standard figure to use for appliances is one million BTU/month and for people, 300,000 per person per month. A two-person household can

be expected to contribute 1.6 MBTU/month. Subtract this from each monthly gross heat loss.

Your south-facing windows *if unobstructed* will contribute to your home heat as well. The exact determination of the amount will be more thoroughly discussed in the SOLAR INSOLATION section. Solar gain charts for different regions are found in the appendix. For sake of completing our chart here, we will go through it in a simple manner now.

The charts for each region tell the number of BTU's that will strike each square foot of your vertical windows each day. Multiply this figure by the number of days in that month and the number of square feet of unobstructed windows to determine the BTU's/month available to your house. This amount is then multiplied by an 80% transmission factor (due to losses caused by glass and wood). The chart shown here describes this process for a house with 30 square feet of unobstructed south windows in Seattle. These figures are also subtracted from the gross heat loss of your home to arrive at the net heat loss.

This calculated number represents the number of BTU's necessary to maintain a house in Seattle at 65°F for the entire heating season. This number can be adjusted to match the number of BTU's that you annually purchase. Performing this adjustment will detail misinterpretations in the analysis to help you become aware of special problems while tightening up your house. It will also give you a dollar value to apply to your analysis so that potential savings may be seen.

Assemble your heating bills for the past few years and try to find the average yearly amount of oil, gas, wood or electricity used to heat your home and the current cost of these fuels. To find the BTU's per unit of fuel purchased, use the conversions shown on this page.

A comparison may now be made between the calculated figures and what really happened in your house. A more detailed analysis may be performed with the help of books listed in the bibliography.

Heat Gain for 30 ft² South-Facing Vertical Surface in Seattle

	BTU/ft ² /day	days/month	total MBTU
J	483	x 31 x 30ft ² =	.5
F	810	28	.7
M	1015	31	1.1
A	971	30	1.0
M	950	31	.8
J	877	30	.7
J	979	31	.8
A	1036	31	1.1
S	1118	30	1.2
O	979	31	1.0
N	683	30	.7
D	433	31	.5

ELECTRICITY: 3412 BTU's per kilowatt
100% efficiency, once in the house.
With 100% electric heat, assume 75%
of your bill is for heating.

NATURAL GAS: 1 therm = 100,000 BTU's
Use a 70% multiplying factor for
furnace efficiency.

OIL: 140,000 BTU's per gallon
Multiply # of gallons used by BTU's/
gallon and by a 70% furnace efficiency
factor (if yours is well adjusted!).

WOOD: 1 cord of alder has 17 MBTU's
A very efficient wood stove will get
75% efficiency, but a fireplace with
a leaky or unclosed damper may take
more heat than it gives.

Heat Loss Calculation for Sample House in Seattle

	degree days	gross heat loss	internal gain*	solar gain	net heat loss
J	784	24.0	1.6	.5	21.9
F	602	18.4	1.6	.7	16.1
M	605	18.5	1.6	1.1	15.8
A	438	13.4	1.6	1.0	10.8
M	269	8.2	1.6	.8	5.8
J	133	4.1	1.6	.7	1.8
J	62	1.9	1.6	.8	--
A	58	1.8	1.6	1.1	--
S	148	4.5	1.6	1.2	1.7
O	335	10.3	1.6	1.0	7.7
N	579	17.7	1.6	.7	15.4
D	713	21.8	1.6	.5	19.7
<i>Figures in MBTU</i>					
*people & appliances					115.0 MBTU

If the calculated heat loss differs substantially from your yearly consumption, adjust the calculated losses by considering these points:

1. If you are maintaining a different household temperature than 65°F, adjust the degree days accordingly. *Be careful!**

Example:

70° - 65° = 5° · 31 days in January = 155 degree days to add to January's degree day column

2. You may need to adjust the infiltration losses if your house is draftier or tighter than you had originally estimated.
3. The wall, ceiling and floor sections may need more exact U value determinations.
4. Your heat gains for the house may be off.
5. Perhaps there is a math error!

When the calculations are adequately adjusted, perform the analysis again, but this time make your house a SUPER CONSERVER house using the figures from the chart below. Compare the two final figures and see what savings are available, both in energy and money. Be sure to note the shorter heating season of the conserving house. Such a house is more comfortable to live in due to less drafts, warmer walls, floors and windows.

Now that you've seen what you can save in your house, let's see what can be gained from the sun.

Heat Loss for a Super Conserver House

Infiltration:	.5 to .75 air changes/hour	
Walls:	U - .055	
Ceiling:	U - .033 - .025	<i>This assumes a decrease in thermal transmission brought about by increasing insulation, double glazing, caulk and weatherstripping.</i>
Floor:	U - .055	
Windows:	U - .38 - .70	

*Be careful! DEGREE DAYS are worked out on a monthly basis due to each month's different highs and lows. For exact degree day changes, consult the *ASHRAE Handbook of Fundamentals* and Bruce Anderson's *The Solar Home Book*.

How to Site Your Solar Greenhouse

The prime consideration in the siting of a solar greenhouse is the availability of sufficient sunlight. The greatest amount of this energy comes from the direction of the southern sky (if your greenhouse is south of the equator, everything is reversed). Prior to making other decisions, a site survey will show you whether there is enough sun to proceed.

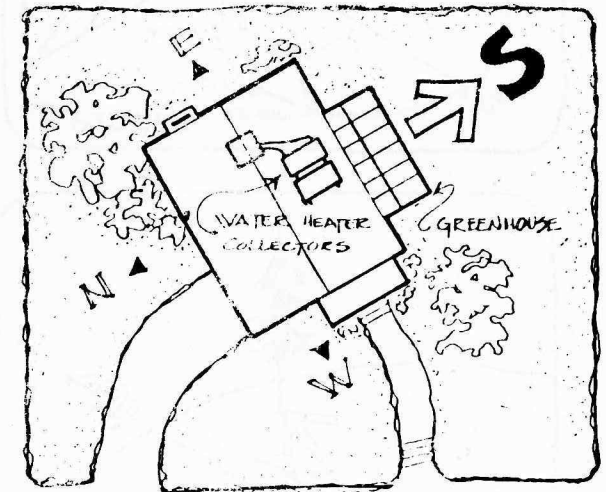
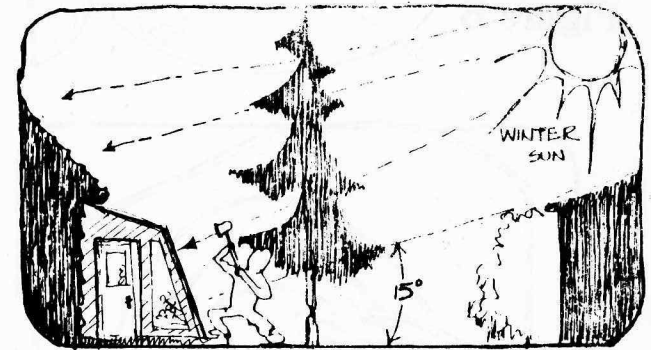
The Site Survey

Walk around your site and become familiar with the obvious obstructions to the sun. At this time, it is valuable to make note on a pad of the types of obstructions and their ownership (e.g., a neighbor's house due south or deciduous trees on the site's property that might block the sun when in full leaf). If you number these comments, these numbers can be used to mark your SUN PATH CHART. Remember that in the winter the sun is much lower in the sky than in summer, and that you are trying to maximize the warmth evenly throughout the year. When you think you have found the best of several possible locations for available sun, ask yourself, "What would it be like here?"

Is the greenhouse close to where the heat will be needed? Is it accessible from the inside of the house? Do people use the south side house rooms? Will it be very difficult to attach to the house? Will baseballs from the local playground keep hitting it? After you have considered all the things that might get in your way -- and you still think this is the right place -- it is time to plot the "skyline" on the Sun Path Chart. (See Figure A.)

Sun Path Chart

The Sun Path Chart shows the sun's location during different times of the day and year. It is used to determine what the potential blockages to light from buildings and terrain would be at the proposed solar collection location. The chart is made by projecting the sun's apparent motion onto a sheet of paper. Figures B and C show how this is done. The chart included with this manual is for 48° north latitude. Seattle and Spokane, as well as Fargo, ND; Duluth, MN; and Quebec City are very close to this. Sun charts for other latitudes in the U.S. are available in *The Solar Guide and Calculator* listed in FURTHER READING.

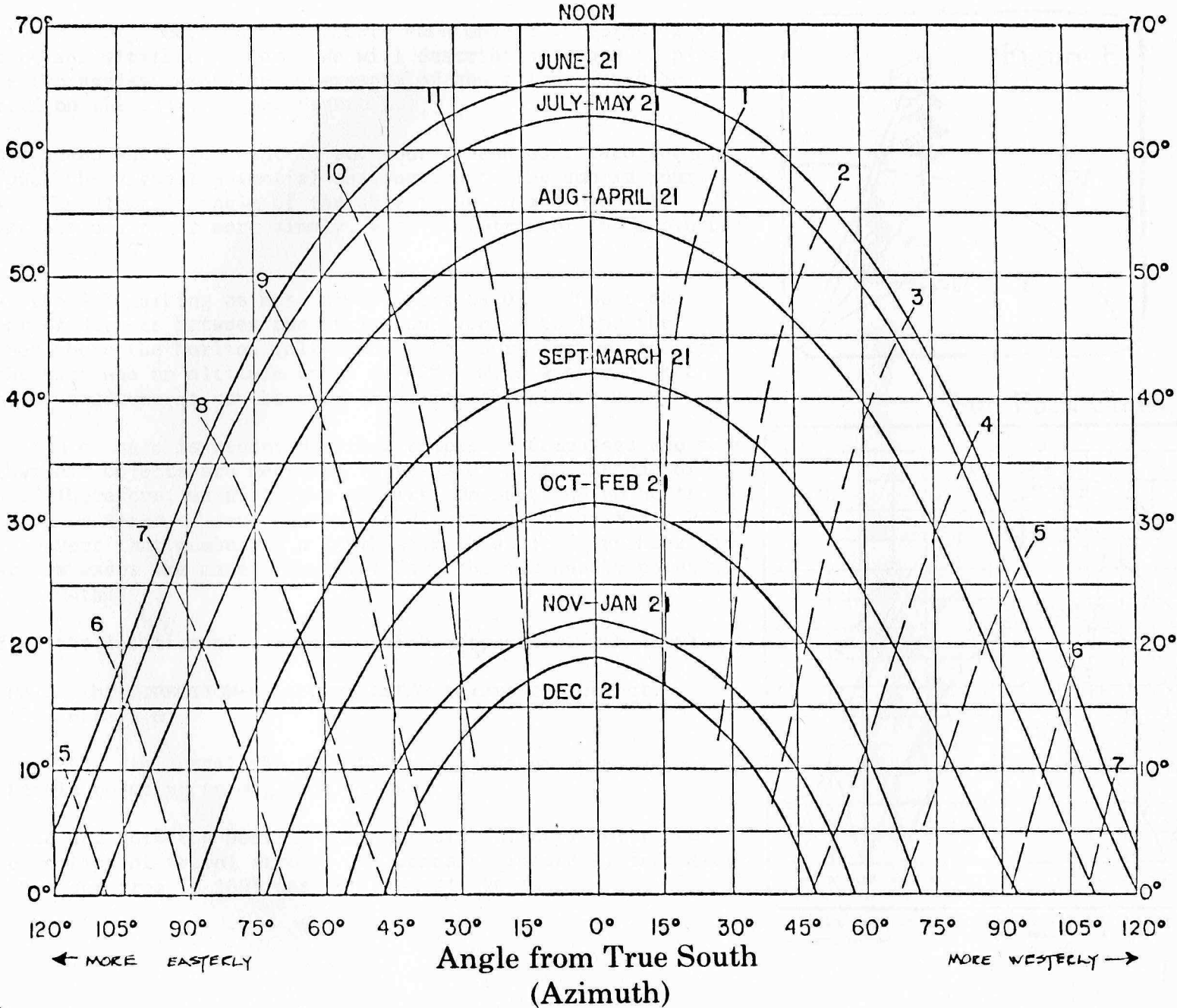


Sun Path Chart

Figure A

21

Solar Altitude



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CUT ALONG DOTTED LINE

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To plot the skyline, you must locate each object in terms of its azimuth and altitude angles. We will describe here how to plot these two angles, and give an example of how a tree would be plotted on the chart. (See Figure L.)

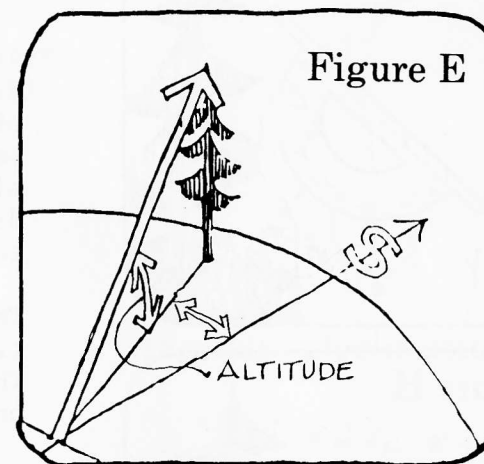
First, stand where you want to put your greenhouse, face south, and pick the highest potential obstruction to the sun in your view. The altitude angle of the object can be measured with either a transit, or more simply, with a protractor and a plumb bob. (Figure G)

Treat the 90° marking on most protractors as 0° . Count the number of degrees between the string and your 0 to find the degrees above the horizon (altitude). For our example, the top of the tree has an altitude angle of 45° . Make a note of the altitude angle so it can be used later for the plot.

The azimuth angle is measured with a compass. Compasses are made so that all objects are measured in terms of north instead of south. Therefore, we will have to first measure the object's location in terms of true north (the direction of the North Pole), then convert that number to a south azimuth angle. (Perhaps when solar compasses are made, they will have the red needle pointing to the south!)

To find the location of the object with respect to true north:

1. Point the DIRECTION-OF-TRAVEL ARROW toward the object. (See Figure H)
2. Turn the dial until the "North" reading lines up with the needle pointing to magnetic north.
3. Read and note the bearing from the dial directly over the direction-of-travel arrow. The compass (Figure I) indicates that our tree is 160° east of MAGNETIC NORTH.



Sun Path Chart

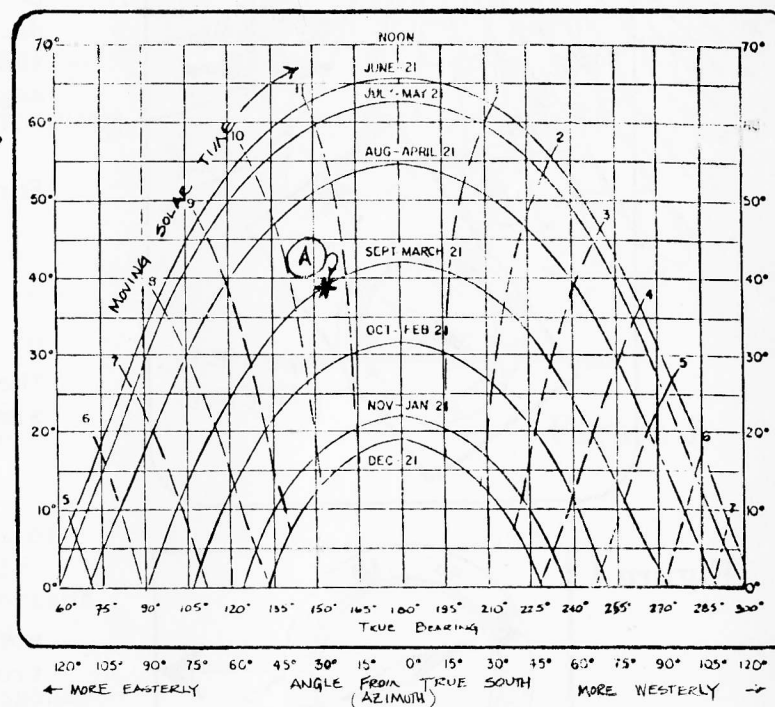
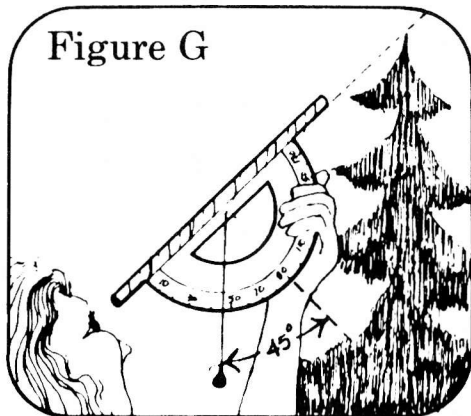


Figure F

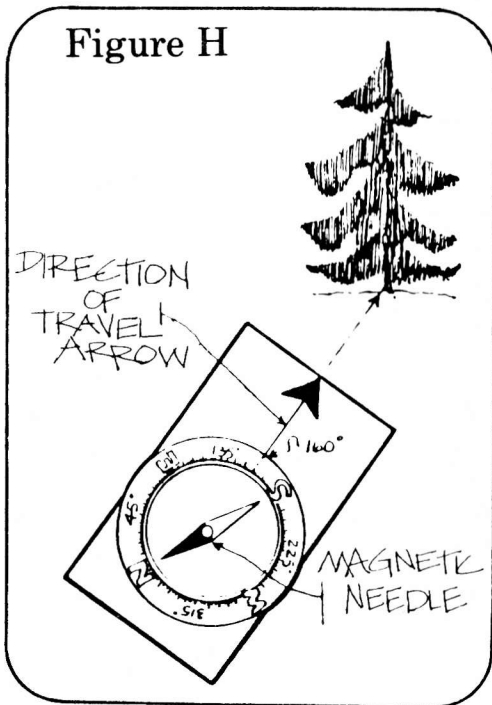
Figure G



As you may know, there are two kinds of north, magnetic north (the direction a compass needle points) and true north (the direction of the North Pole). Magnetic north and true north are not the same in most locations. Since the magnetic field varies and moves slowly over the earth's surface, it is necessary to know the difference for your locale between magnetic and true north (called the DECLINATION).

The magnetic needle's north end either points farther east than true north (east declination) or farther west (west declination). The declinations for locations in the United States are marked on the map below. Seattle's declination is 22° east.

Figure H



Once you know your declination, you can calculate the true bearing from the magnetic bearing in the following way: when magnetic bearing is east of true north (that is, when you are west of the 0° declination line shown on the map), ADD the declination from the magnetic bearing to produce the true bearing. When the magnetic bearing is west of true north (when you're east of 0°), SUBTRACT the declination to find the true bearing. (Figure J)

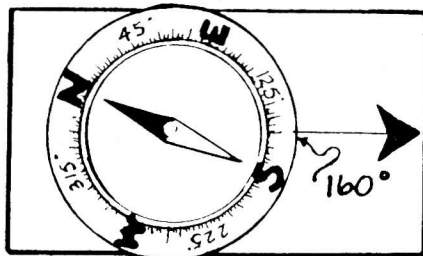
For our example, since Seattle is 22° east, the true bearing is:

$$\begin{array}{rcccl} 160^\circ & + & 22^\circ & = & 182^\circ \\ \text{(magnetic)} & & \text{Seattle} & & \text{true} \\ \text{bearing} & & \text{declination} & & \text{bearing} \end{array}$$

The tree is therefore 138° east of true north. To find the azimuth, simply subtract 180° from the true bearing:

$$\begin{array}{rcccl} 182^\circ & - & 180^\circ & = & 2^\circ \\ \text{(true north)} & & \text{conversion} & & \text{(east of)} \\ \text{bearing} & & \text{number} & & \text{south} \\ & & & & \text{bearing} \end{array}$$

Figure I



NOTE: If you obtain a negative number, your reading is east of true south. A positive number is west of true south. (Figure K)

Now we have it! The tree has an azimuth angle of 42° east of true south. Now we can plot the tree (or your particular obstruction) on the Sun Path Chart. To do this, mark the point on the chart represented by the altitude and azimuth angles (42° east, 45° -- that is, the top of the tree). The rest of the tree can be sketched in, or you may measure directly other points of the obstruction the same way the top was measured.

Go through this procedure for all obvious obstructions, and connect the points to complete the skyline. You will have to determine whether or not this represents too much shading.

Not all the areas on the Sun Path Chart are as valuable for solar heat as others. This is partly due to the greater amounts of atmosphere that low-angled sunlight must pass through, and partly due to the particular climate of your area. An example of this latter effect would be consistent early morning fog that would make an effective shadow covering the early morning (easterly) area of the chart. A detailed analysis could be done hour-by-hour using *The Solar Guide and Calculator* (see FURTHER READING) and information about your local weather patterns. A more simplified approach follows here.

The evaluation of the Sun Path Chart for your greenhouse is the next problem. The area in Figure L outlined by the heavy line contains virtually all the direct solar energy available to a southfacing greenhouse. A solar greenhouse requires a good deal of solar energy to maintain its temperature in the winter, spring and fall. However, in the summer much of the available solar energy should be shaded to prevent overheating.

In general, Area A in the winter months contains only about 15% of the total annual solar energy that falls on the greenhouse. If the greenhouse is to be used for winter crops, it is very important to get all the light possible, so obstructions in this area are crucial and can affect the operation of the greenhouse. If surplus heat is to be used in the house, this area also corresponds

Magnetic Declination Adjustment

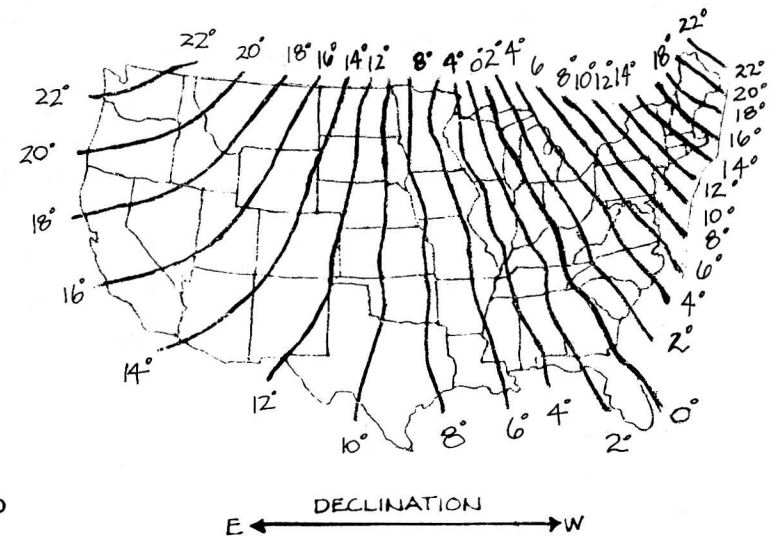


Figure J

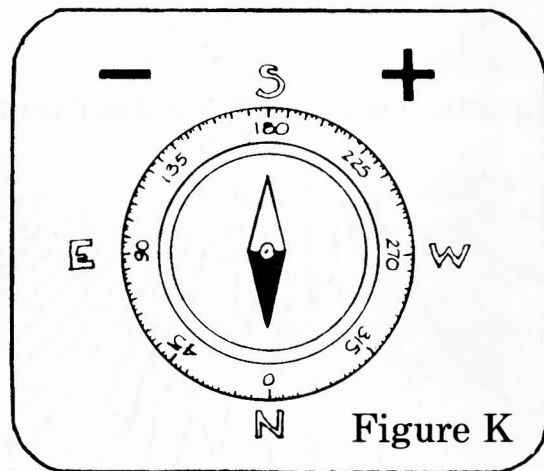


Figure K

to times of greatest heat demand and hence times when the greenhouse could be very useful as a heater.

Area B represents the most productive time for the greenhouse. About 40% of the annual solar energy occurs during this period; it is the time when new spring planting sets are begun or when the greenhouse extends the summer growing season into October for warm weather crops. In this period a well-designed greenhouse coupled with a well-insulated house can substantially reduce or eliminate the heat demand of the house. The actual operation of the greenhouse during this period will include venting and/or shading to insure cooler temperatures. This means that movable shading may be desirable or deciduous shade plants may be usable. Shading from deciduous trees becomes significant from April through October, although other plants such as grapes, pole beans, and peas can be used as seasonal shade plants.

Area C includes the remaining 45% of the year's solar energy. In general this is too concentrated and direct for successful greenhouse operation so some shading must be done. One option is to have an overhang that shades sun altitudes higher than 55° . If the roof is 8' above the ground, an overhang of 5.6' would be necessary to shade the entire back wall, and much more to shade the entire greenhouse growing space. Except in rare instances, this problem is best solved by movable shades.

If the potential for solar heating is to be evaluated, then Area A and Area B are the relevant sun times. Area A represents about 30% of the total radiation during this heating season, while Area B represents the remaining 70%.

So shadows are multiplied by their factors. A sample calculation would be:

A tree that is obstructing 30% of Area A and continues up to obstruct 20% of Area B reduces the solar greenhouse heat collection by:

$$\begin{array}{ccccc} (.3 \cdot .3) & + & (.2 \cdot .7) & = & .23 \text{ or } 23\% \\ \text{A} & & \text{B} & & \end{array}$$

If the tree in question is a deciduous and not an evergreen tree, it gets a little more complicated since in winter (Area A) the tree will have lost its solar-blocking leaves and will then block only about 25% of the light. This can be incorporated into the above equation by multiplying the first term deciduous tree areas, if they occur, by .25. The shading potential can be determined in the same way for Area C, only this time the larger the number, the more effective the shading device.

If after doing the calculations you find that the greenhouse's effectiveness will be reduced by 40% or more and there is no way to move either the greenhouse location or the obstruction, you may find that the economics do not look suitable, i.e. that the greenhouse will not pay back its operation. At this point, the best thing may be to put more of that hard-earned money into additional home insulation, weatherstripping, or other types of conservation techniques that are not dependent upon the solar energy at your site.

Sun Path Chart

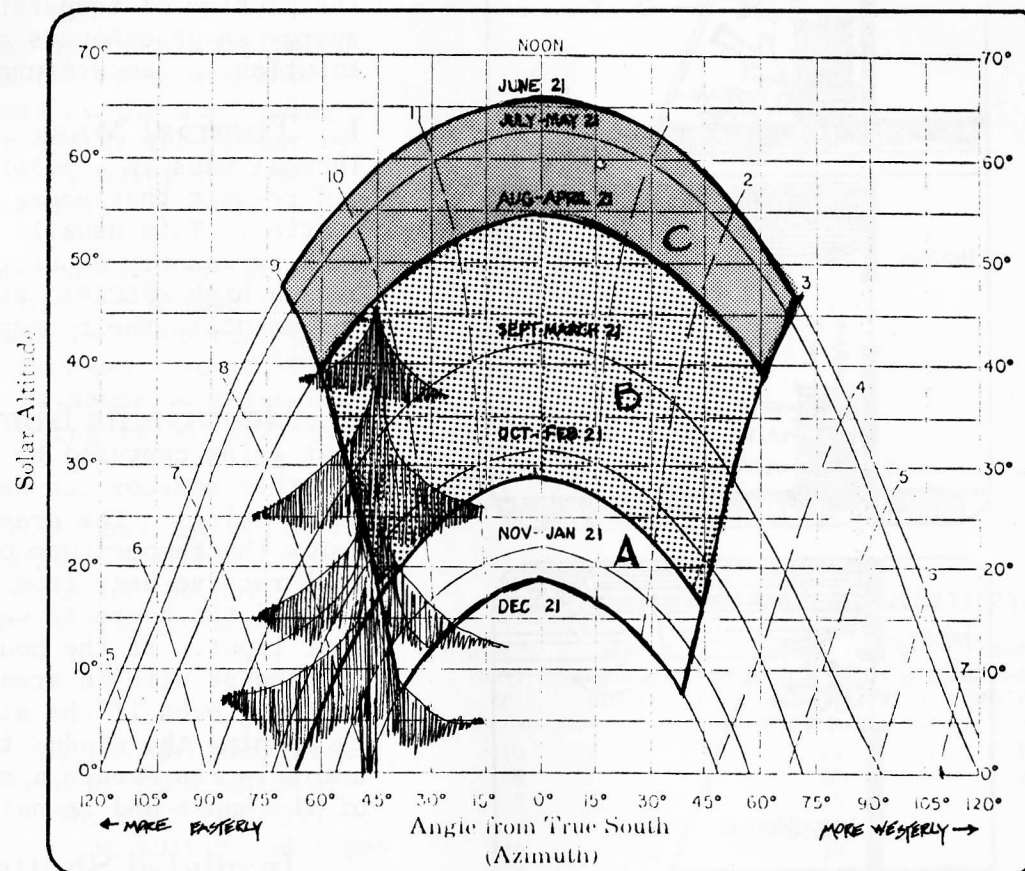
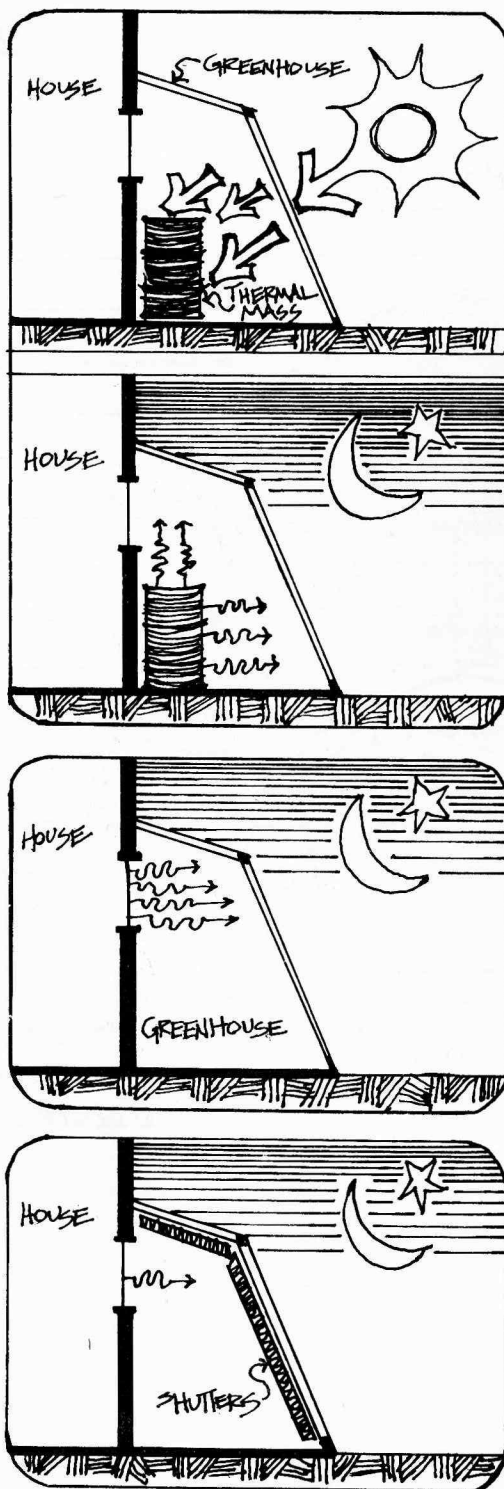


Figure L



drawing by Susan Gross

Freeze Protection and Heat Storage

The problem of temperature maintenance arises when using solar energy in greenhouses on a cold cloudy day or at night. The solution to temperature problems can be one of three options:

1. Thermal Mass

Thermal mass in a solar application is used to absorb sunlight and re-emit that energy as heat in the absence of direct solar heating. This usually takes the form of very massive materials such as masonry or water. These materials are very dense and have a high SPECIFIC HEAT, therefore they gain heat from sunlight but maintain their temperature longer than surrounding material or air.

2. Heat Gains from Attached Houses

Heat gains captured by the greenhouse from the attached houses or other sources can help to moderate internal greenhouse temperature swings. The greenhouse temperature is at times substantially below the temperature of the house. As a result, the greenhouse will receive heat from the house through the walls and windows. Even if the house is well insulated, this amounts to a substantial heat input. If the house has a window(s) that faces into the greenhouse with an area of 40 ft², the greenhouse will stay above freezing even if the night temperature falls to 24°F. Obviously, by opening the window this house could actually heat the greenhouse, but this represents a substantial increase in the fuel requirements of the house and is not recommended.

3. Insulated Shutters

Insulated shutters or curtains reduce the heat loss through the greenhouse glazing. If in the previous example you installed a 1" Styrofoam[™] shutter over the greenhouse at night, the heat loss from the house through the closed window would protect the greenhouse from freezing down to -2.6°F. There are several options available for such shutters. The simplest is a rigid insulating board cut to a size that fits exactly between the window mullions and can be stored easily in a closet in the daytime. More elaborate solutions include insulated quilted curtains or hinged insulated doors with wood frames and magnetic catches. In colder climates, especially eastern Washington and Oregon, such insulation will probably be essential to insure year-round frost-free growing conditions.

Freeze Protection

The greenhouse is kept above freezing, then, by a combination of heat given to the space by heat losses from the house and heat given off by the storage mass that was warmed by the sun during the day. When designing your greenhouse, consider the amount of mass required to maintain temperatures above freezing in your climate. Guidelines for this are provided below.

If you are building the greenhouse for home heat supplement or are not using it for winter planting, mass becomes unimportant since the night temperature of the greenhouse is of no consequence to the house. Any additional mass in the greenhouse would absorb heat that would otherwise be available to the house. If you are using your greenhouse in this way, the following is not pertinent to your design.

To design your greenhouse for protection from freezing, estimate the heat gains from the house through the window and heat gains from the thermal mass that collected energy during the day. This is balanced against the amount of heat lost by the greenhouse on the coldest day.

Sizing Thermal Mass

To estimate the quantity of heat stored by the thermal mass, use the SPECIFIC HEAT -- the amount of heat stored by each pound of material when its temperature is raised 1°. The HEAT CAPACITY of any thermal mass is shown by the specific heat multiplied times the number of pounds of material present. (See Table 3) To size thermal mass for a greenhouse, determine the amount of heat capacity by the amount of glass that accepts sunlight in the day and loses heat at night. Table 1, THERMAL MASS COMPUTATIONS, allows you to determine how much heat capacity your greenhouse requires *per square foot of glass* to prevent freezing at a given night temperature.

For example, if you live in Moses Lake, WA, the coldest temperature that is "likely" to occur is 0°F. If your greenhouse is to be double glazed, then you would use 15 BTU/ft²-0°F of equivalent

Thermal Mass Computations

<i>design temp °F</i>	<i>mass for single glazing BTU/ft²/°F</i>	<i>mass for double glazing BTU/ft²/°F</i>	<i>mass for shuttered glazing BTU/ft²/°F</i>
-10	*	25	10
-5	*	20	10
0	*	15	5
5	30	15	5
10	25	10	-
15	20	10	-
20	15	5	-
25	10	5	-
30	5	5	-

Table 1

Material to Meet Mass Requirements

	Mass Required (from Table 1)					
	5	10	15	20	25	30
water (gallon)	.6	1.2	1.8	2.4	3.0	3.6
rock/ft ³ (loose fill)	.2	.4	.6	.8	1.0	1.2
concrete (ft ² @ 6")	.3	.6	.9	1.2	1.6	1.9
brick (4"x4"x8")	2.7	5.4	8.1	10.8	13.5	16.2

Table 2

Mass Calculations

$$S = M (G - 2W/K_I)$$

S = number of units of storage
(gallons of water, number of bricks,
cubic feet of rock per ft² of glass)

M = number from MATERIAL TO MEET MASS
REQUIREMENTS (Table 2)

G = square feet of glass

W = window area of house facing on
greenhouse

K = number of glazings on windows

* constant

equivalent storage mass. This actually describes the amount of storage mass that would be required to keep the greenhouse above freezing on the night when the outside temperature falls to 0°F. You could multiply this number by the amount of glass in your greenhouse -- but wait. First we will get more specific.

Look in Table 2, AMOUNT OF MATERIAL TO MEET MASS REQUIREMENTS, to determine the mass needed to prevent freezing. If you use different material than shown in this table, simply take its specific heat and density from Table 2 and divide into the mass requirement. This will give you the number of mass units equivalent to those in Table 2.

Now take this number and substitute it into the MASS EQUATION shown in the left margin to determine the amount of mass required. In the Moses Lake example, if we were to decide that our mass was to be 55-gallon drums filled with water, we would look in Table 2 to determine the number of gallons of water required for heat storage (1.8 gallons per ft² glass). If the greenhouse had 150 ft² of glass and covered a double glazed window that is 20 ft² (5'6"x3'8"), then the computation would be:

$$\begin{array}{cccccc} 1.8 \text{ gal/} & \cdot & \{ 150 - 2^* \cdot (20 & \div & 2) \} = & 234 \text{ gallons} \\ \text{ft}^2 \text{ glass} & & & & & \\ \text{(amount of material} & & \text{(ft}^2 & & \text{(ft}^2 & & \text{(\# of} & & \text{(total amount} \\ \text{to meet mass} & & \text{glass)} & & \text{window} & & \text{window} & & \text{of mass for} \\ \text{requirement from} & & & & \text{from} & & \text{glazings)} & & \text{greenhouse)} \\ \text{Table 2)} & & & & \text{house)} & & & & \end{array}$$

If this water is put in 55-gallon drums, then divide 234 by 55 to find the number of water drums required. Remember when sizing mass for freeze protection, always be on the safe side. If an extra barrel can be easily installed, it may help you through the 50-year hard freeze.

A few cautions before you proceed: The mass computations are based on a certain surface area that is illuminated by the sun. Once you know how much mass to install, you should be careful that you

place the mass so that the sun shines on it. If you choose masonry, then be sure that the mass is thin enough. If concrete or brick is used, we recommend that only the first 4" to 6" of the wall thickness be considered mass.

Heat Storage

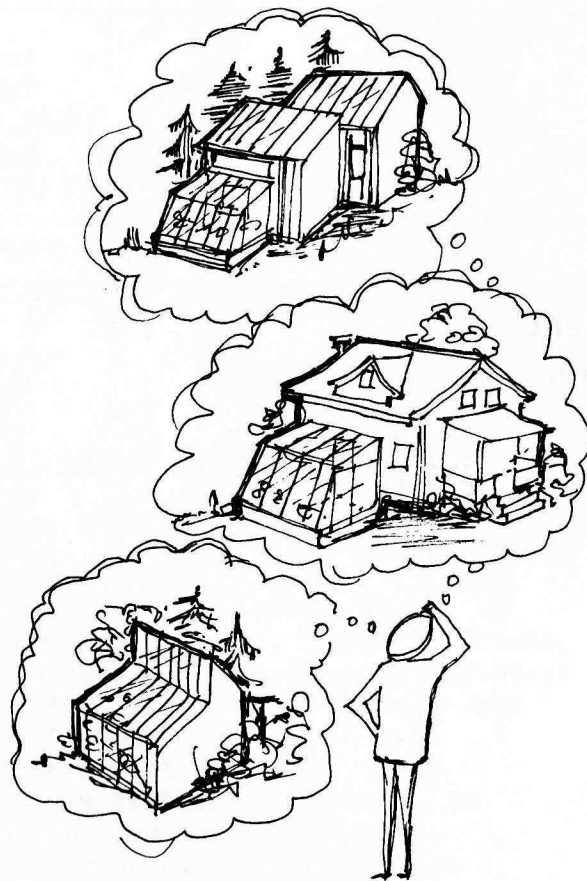
If the storage mass is to be used for the house's heat storage, the total mass should be about 50 BTU/ft²-°F. The amount of mass in the greenhouse for freeze protection is deducted from the total. The balance can be placed in the house for heat storage. The details of this are more complicated than the scope of this book permits for discussion. Read more about it in *The Solar Home Book* by Bruce Anderson and *Natural Solar Architecture: A Passive Primer* by David Wright. Further reading and talking with solar design consultants such as ECOTOPE GROUP can help you to easily solve this problem.

Heat Capacity and Specific Heat of Common Building Materials

<i>material</i>	<i>specific heat</i> BTU/lb-°F	<i>density</i> lb/ft ³	<i>heat capacity</i> BTU/ft ³ /°F
<i>water</i>	1.00	62	62
<i>steel</i>	0.12	490	59
<i>rock or stone</i> <i>(30% voids)</i>	0.21	120	25
<i>concrete</i>	0.23	140	32
<i>brick</i> <i>(10% voids)</i>	0.20	134	25
<i>oak</i>	0.57	47	27
<i>sand</i>	0.19	95	18
<i>pine or fir</i>	0.67	27	18
<i>clay</i>	0.22	63	14

Table 3

Designing Your Greenhouse



The design possibilities for solar collectors enclosing living space are as broad as all of architectural design. Although we can't attempt to cover a diversity of designs, we can offer a quality design which can be adapted to your size, style or cost needs.

Since an attached greenhouse doesn't involve any major structural modifications to your home, it offers immediate solar implementation. In addition, the design and construction processes described here offer an introduction to techniques and a reinforcement of the idea that one need not possess professional "mystique" to construct a building.

As an example of the design process for a solar greenhouse, we are presenting here questions and parameters that are involved when we design our standard 10x16' attached greenhouse in preparation for a workshop. The development of a construction-ready design follows these guidelines:

1. The site of the greenhouse is on a well-insulated home with a good percentage of unobstructed south sunshine.
2. The greenhouse should cover one or more windows or doors for an effective heat transfer to the house.
3. The greenhouse should present as large a south-facing clear surface as the site and cost will allow.
4. The site should not present any major construction obstacles for connecting with the house or for placement of the foundation.
5. The location should be fully accessible and appropriate for the use of the greenhouse and should not block any commonly used walkways.

Answering these next questions can help define the design:

1. Are you designing with standard-sized materials in mind (to avoid waste) and with the structural limitations of these materials?

2. Which construction details will define the size and shape?
3. Will your design incorporate well thought-out building techniques?
4. Will the design meet zoning and structural code requirements (if necessary) in your area?

Sketching the Design

When the best site has been determined, the initial design step is sketching the site from the side, front and above, incorporating the dimensions and locations of all windows, doors, roofline, grade and any obvious obstructions to the structure. With an architect's rule, draw up the sketches to scale and develop a feeling for the interrelationship of all the parts.

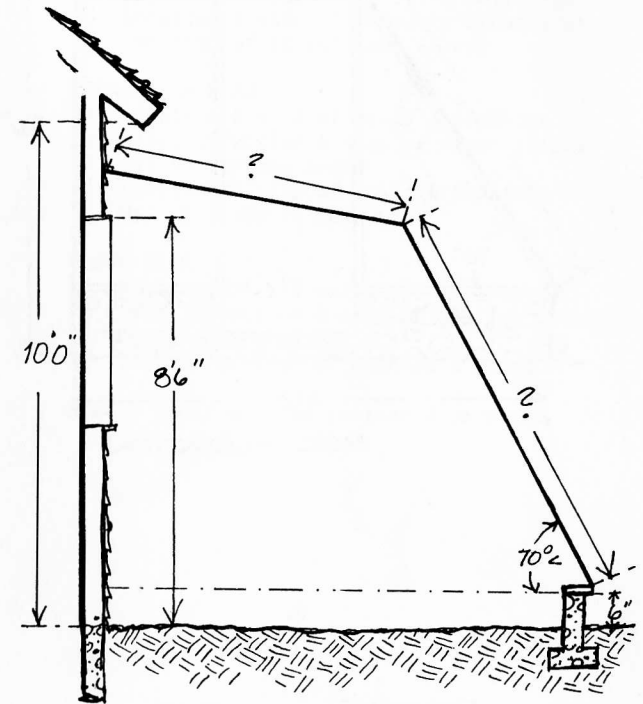
Working with the dimensional materials in mind, begin "applying" your greenhouse to the site by drawing it to scale. This sketching process helps you to begin some creative designing, as well as pointing out the limitations of the site -- problems not immediately apparent will now leap out at you! It's good at this point to work with these sketches for a couple of weeks -- the decisions made at this point will be around for a long time.

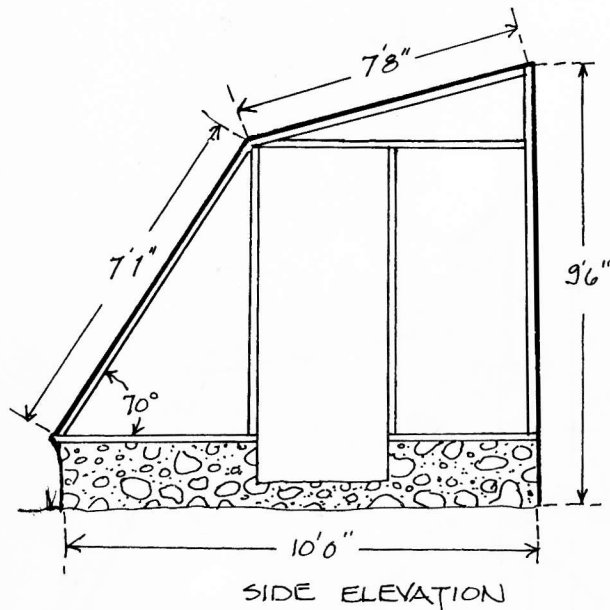
The Workshop Greenhouse Design

The workshop greenhouse shape is one commonly used for solar greenhouses because of its easy use in many different situations. Alterations can be done with some slight variation of angles and lengths of materials while still using standard material sizes.

The ECOTOPE workshop greenhouse is designed with the following parameters:

1. The roofline drops to 10' above grade.
2. The east and west wall window frames rise to $8\frac{1}{2}'$.
3. The greenhouse is 10' wide.
4. Code requires a 6" stem wall at the foundation.





5. Standard sheets of glass are 7' long and other materials are standard sizes of 8', 10', 12', 14', 16' and 20'.

6. As vertical a south face as possible is good for head room.

By incorporating a 70° south face with a height of 9½' at the back, we can work within standard material sizes and make use of the 6" stem wall needed for code. A more vertical face would require longer rafters -- therefore more substantial lumber. The 10' width of the greenhouse is a good size to work with when laying out the interior. It breaks down nicely into two 3'9" beds and a 30" walkway.

Now that the greenhouse is properly located and sized, we can begin drafting it, which will determine exact overall dimensions, locating doors, vents and solid walls. From the final drawings, a complete and accurate materials list can be developed to determine the cost of the structure. When you do the working drawings, you will solve many construction problems while they are still on paper. A proper working drawing will also be necessary for obtaining a building permit.

The Code

These guidelines are for Seattle. Check with your local building department for variations.

There are basically five requirements that have to be met to obtain a building permit. Pamphlets are available detailing the basic requirements and will usually be helpful in determining the integrity of a structure you have designed.

1. **ZONING:** The building department requires that only 35% of a city lot may be covered with buildings. An addition must be 5' back from property lines at the side yard and 25' back from the front and rear property lines.

2. **MATERIALS:** A structure must be built of properly sized structural materials and meet code building practices. Check your design with a carpenter-friend to see that you have done this.

3. **THE FOUNDATION:** The foundation or footings must sit a foot below grade on undisturbed earth with a 12" wide foot and rise 6" above grade. This is done with a footing 6" thick and 12" wide supporting a 6" wide **STEM WALL** that rises to 6" above grade.

4. **WINDOWS:** In covering windows, the building department, to insure adequate ventilation, requires that there are openable areas equal to 10% of the floor area of each room. This is a debatable point as we will be using the greenhouse for ventilation, but this is a new area for the building department so some changes will be necessary. If this is a problem for you, try to get a variance. This law is protecting you from a problem you aren't creating.

5. **GREENHOUSE AS LIVING SPACE:** If your solar collector is for additional living space other than a greenhouse (living room, dining room, kitchen addition), any overhead glass must be tempered plate or wire glass. If it is indeed a greenhouse, double strength glass overhead is fine. The determination of whether an attached greenhouse is a greenhouse or not is up to the individual building inspector. There are no clearly defined guidelines to work with in this situation.

In order to get a building permit, a plan must be submitted detailing the lot, the foundation and the structure. The requirements are shown in the margin here.

The Glazing System

Glazing refers to the transparent or translucent material used to cover the south side of the greenhouse. It can be either rigid like glass and acrylic ("Plexiglass," "Acrylite") or semi-rigid like fiberglass-reinforced plastic ("Kalwall," "Filon," "Lascolite").

ECOTOPE uses glass for the glazing in its solar greenhouses. Glass is durable, elegant and allows a large percentage of sunlight to pass through it into the greenhouse. While many fiberglass products advertise that they transmit light as well as glass does, they are referring only to **DIRECT** light. In fact, fiberglass will reflect a comparatively large amount of **DIFFUSE** light.

PLOT PLAN:

- 1) Name & address of owner
- 2) Legal description of property
- 3) All property lines dimensioned
- 4) Location & size of existing buildings
- 5) Location & size of property structures
- 6) Location of streets and alleys

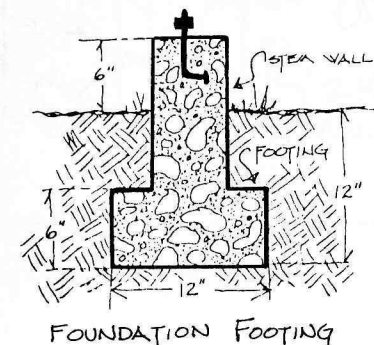
FOUNDATION PLAN:

- 1) Location & size of walls & footings
- 2) Size, direction & span of floor joists
- 3) All supporting beams
- 4) Location & size of posts & footings
- 5) Use of areas in basement

FLOOR PLAN:

- 1) Location of all walls
- 2) Size, direction & span of ceiling joists
- 3) Use of all areas
- 4) Size & location of windows & doors

Note: Above must be indicated on plans



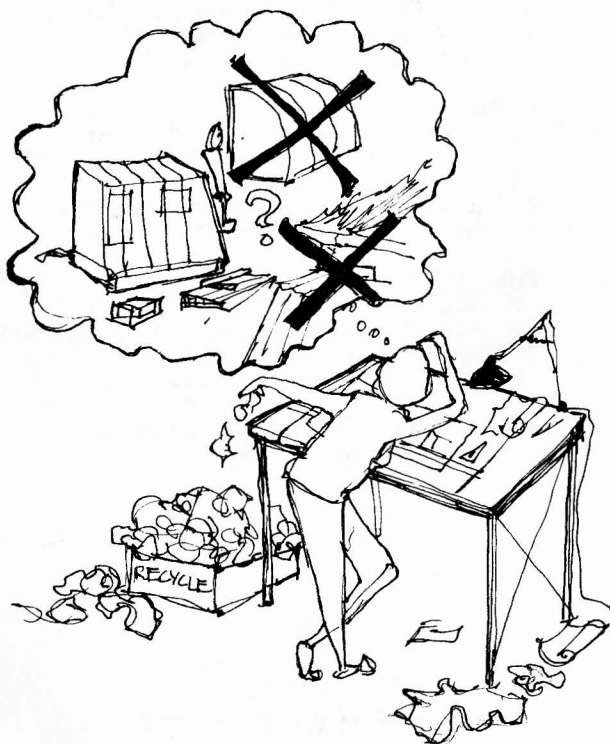
Qualities of Glazing Materials

Glazing Material:	shortwave transmission (% of total)	longwave* transmission (% of total)	relative environmental stability	cost**
Rigid:				
window glass 1/8"	87%--varies with lead content	3-8%	excellent if not broken	medium- high
tempered glass	similar to window glass	3-8%	excellent breakage resistant	high
acrylic -- 1/8" (Plexiglass)	about 85%	3%	good [†]	high
Acrylite SDP (double skinned acrylic)	83%	3%	good [†]	high
Semi-Rigid:				
regular fiberglass flat - 25 mil	about 70%	6-12%	poor	medium
polyvinyl fluoride- coated corrugated fiberglass--40 mil (Filon, Lascolite)	79%	7-8%	fair	medium- high
Films:				
polyethylene 4 mil	70-88%	70-80%	poor (6 months)	low
polyester 5 mil (Mylar)	about 85%	16-32%	good mechanically; good UV resistance	low- medium
polyvinyl fluoride 4 mil (Teflon, Tedlar)	90-94%	43%	Teflon: excellent Tedlar: mechanically poor; good UV resistance	low- medium

*Longwave transmission is only one of several measures of how well a material keeps heat from escaping. None of these really gives a complete picture. This measure was chosen for simplicity and consistency.

**Cost varies greatly with source of supply.

†Acrylics have a high coefficient of linear thermal expansion. Acrylite will expand about 1/8" in a 4' panel with a 20° temperature rise.



Diffuse light is especially important in a climate with relatively few completely clear days (like the maritime Northwest). Especially in the winter when you need the greenhouse the most, it is important to make as much use of the diffuse light as possible. If, on the other hand, you live east of the Cascade Mountains where there is a great deal more direct sunlight during the winter, you may find that a fiberglass product treated to resist ultra-violet deterioration will work for your greenhouse. If you use fiberglass, you will want to use a different glazing detail than we show in this GUIDE.

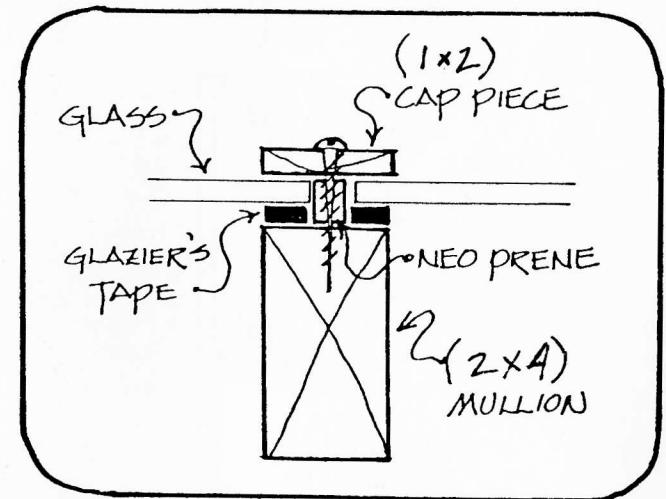
We still think you'll be happier with glass. Although glass is often more expensive than fiberglass and plastic products, the extra expense only amounts to 10% of the total cost of the structure. The extra expense will pay for itself in increased light gain for the greenhouse and increased aesthetics of the structure.

Another important consideration is the use of multiple glazings. A double glazing will reduce heat loss, but it represents a larger expense and cuts 10-20% of the sunlight transmitted into the greenhouse. In some climates where winter evening temperatures are low, double glazing is essential. In more mild climates, thermal mass can replace the protection provided by an extra glazing.

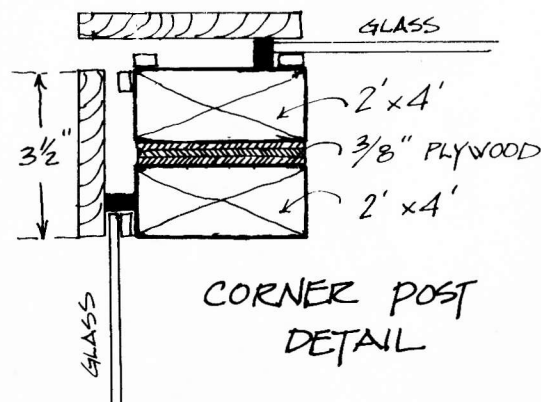
To determine the transmissivity of a double glazing, multiply the transmissivity of each glazing (see table on QUALITIES OF GLAZING MATERIALS). If you are using a double glazing of glass and polyvinyl fluoride, for example, the transmission of the total glazing will be:

$$\begin{array}{rcccl} .87 & \cdot & .90 & = & .78 \\ \text{transmission} & & \text{transmission} & & \\ \text{of glass} & & \text{of polyvinyl} & & \\ & & \text{fluoride} & & \end{array}$$

In addition, thermal shutters or drapes can be added to reduce night heat losses. This is extremely effective -- a good insulating curtain or shutter can substitute for a second glazing. If you decide to install shutters, *you must be certain that they will be used*. Their heat-loss-reducing-effectiveness will be immaterial if they remain stored in a corner while the plants freeze.



GLAZING DETAIL



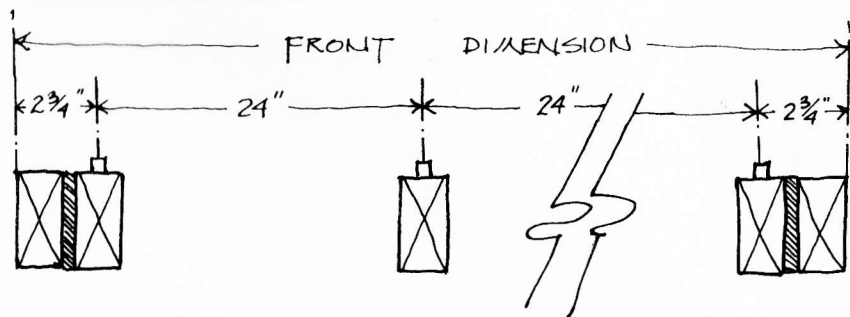
Since standard spacings for lumber in wood frame walls are 16" and 24" and since most building materials work within these standard dimensions, it is good practice to stick to them in the glazing detail. Glass comes in standard 4'x7' sheets. We have them split into two sheets 23 $\frac{1}{4}$ "x7'. This will allow the MULLIONS to remain on 24" centers with a space in between the strips of glass.

In order to form an airtight, waterproof seal and avoid expensive machinery to detail the lumber, we secure the glass with neoprene sponge rubber and GLAZIER'S TAPE held tight with a wooden CAP STRIP. The neoprene sponge should be locally available in 3/8"x3/8" strips from gasket, rubber products or packing companies. The glazier's tape (1/8"x3/8"), either regular putty tape or the better butyl glazier's tape (Tremco 400_{tm}) is available from glazing, greenhouse or sealant companies.

The neoprene sponge rests between the sheets of glass on the mullions, with the strips of glazier's tape between the glass and the mullion. A wooden cap strip is screwed down on top of the mullion, compressing the neoprene and sealing the glass against the tape.

The screws used are FLAT HEAD, SQUARE-DRIVE SHEET METAL SCREWS #10x2". Instead of a slot, they have a square hole in the top. When used with a square driver purchased with them, they are a very positive, non-slip securing system. The square drivers may be used in a screwdriver handle, in a bit and brace, or in a variable speed electric drill. These are also called *Robertson screws*.

The length of the mullions needs to be sized so that the glass overhangs above and below $\frac{1}{2}$ ". If the south face slopes, we notch the bottom of the mullion and lay in a 1x2. With the glass lying over this, it creates a mullion 7'1" long. (See working drawings.) See illustration on page 30.



To find the exact length of the greenhouse, the corner posts must be taken into account. We sandwich a piece of 3/8" plywood in between two 2x4s to give a square 3 $\frac{1}{2}$ " corner post. An eight "light" greenhouse will then be $8 \cdot 24" + 2 \cdot 2 \frac{3}{4}" = 16'5\frac{1}{2}"$ long.

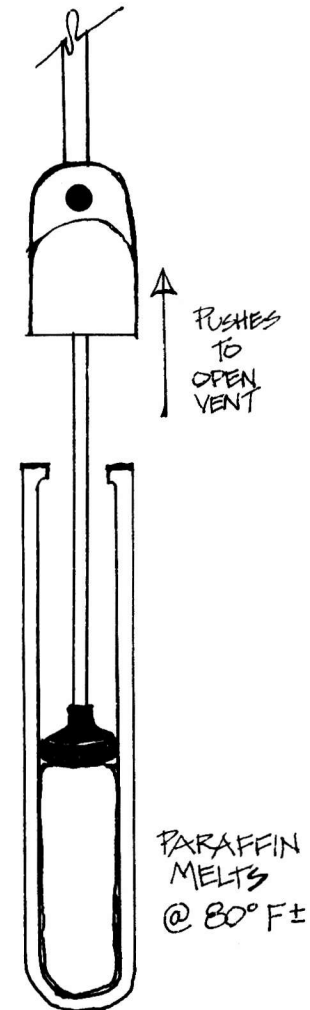
The greenhouse is now 10'x16'5½", and the foundation can be built to the same dimension. Or we can incorporate the foundation insulation into these dimensions so that the outside surface of the greenhouse will be on the same plane as the outside surface of the insulation. This eases flashing problems and leaves a more professional appearance. The perimeter insulation is made up of 2" structural styrofoam. Subtracting 2" from each end and from the front of the greenhouse, the foundation's outside dimensions become 9'10"x16'½". The sill for the greenhouse uses a 2x6 cantilevered over the styrofoam.

Vents

Vents and fans are used to control the internal temperature of the greenhouse. The ECOTOPE workshop greenhouse includes two external vents -- one high and another low vent on an opposite wall. The vents are manually operated (this means you have to go out to the greenhouse and open them). With the two vents (and sometimes the door!) open, cooler air comes in through the lower vent and the additional air pushes the hot air at the top of the greenhouse out of the upper vent. An additional vent lets greenhouse air into the house, to be opened when warm greenhouse air is needed to heat the house.

There is no fixed number of vents required. A rule of thumb for deciding on vent area is the equivalent of 1/10 of the floor area of the greenhouse for operable vents. If you use a fan or thermal stack, this won't apply.

One improvement you may make on venting is to install a "heat motor" to automatically open and close the vents. Heat motors can be found in greenhouse supply shops and through such publications as *Sunset* magazine. These are like small pistons -- a spring encased in paraffin. When the paraffin melts at (say) 85°F, the spring is free to contract and pull the vent cover open. This venting technique for air flow into the house or through the greenhouse can be assisted by use of small fans placed in the vent openings. Very small (1/20 hp) fans with thermostatic controls can be purchased for \$20-\$30.



HEAT MOTOR

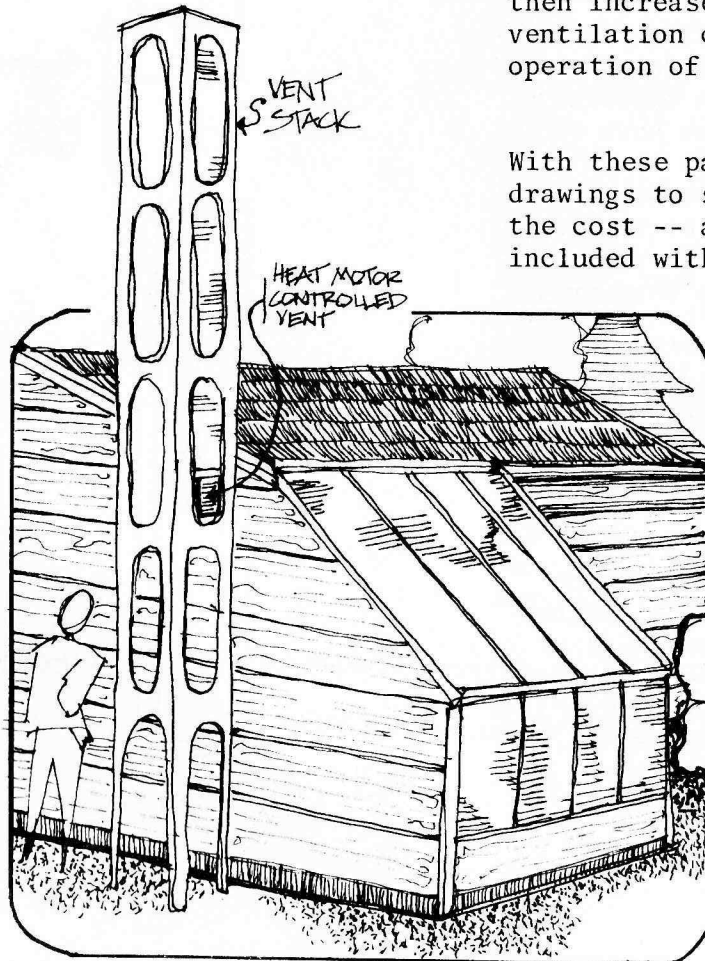
drawing by Susan Gross

These fans are useful for bringing warm greenhouse air into the house or for moving the hot air that rises to the top of the greenhouse down to where it can be used. A recirculation stack with a fan is useful for sucking this hot air -- useful in both a greenhouse and your home if you have problems with hot ceilings and cold floors.

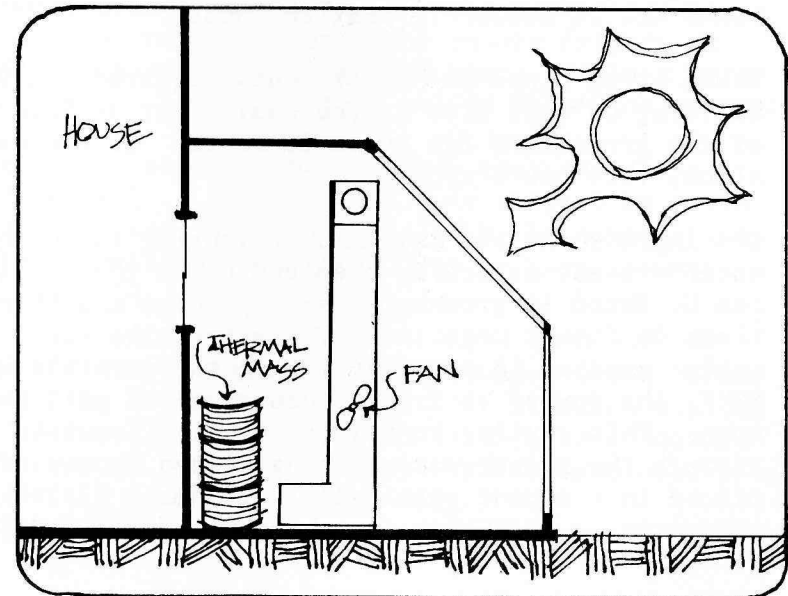
THERMAL STACK

A variation on the vents used to cool the greenhouse is a THERMAL STACK. A greenhouse can use a chimney, applying the stack effect and natural convection. In addition to the stack effect, solar boost can be created by glazing the chimney's south face to increase the temperature in the insulated stack. Ventilation then increases in phase with solar heat gain. In a thermal stack, ventilation can be controlled by either a heat motor or manual operation of the stack opening.

With these parameters for the design, you can finalize working drawings to scale, solve any problems with the design, determine the cost -- and get to work! An example of a working drawing is included with this book.



drawing by Susan Gross



RECIRCULATION STACK

Construction

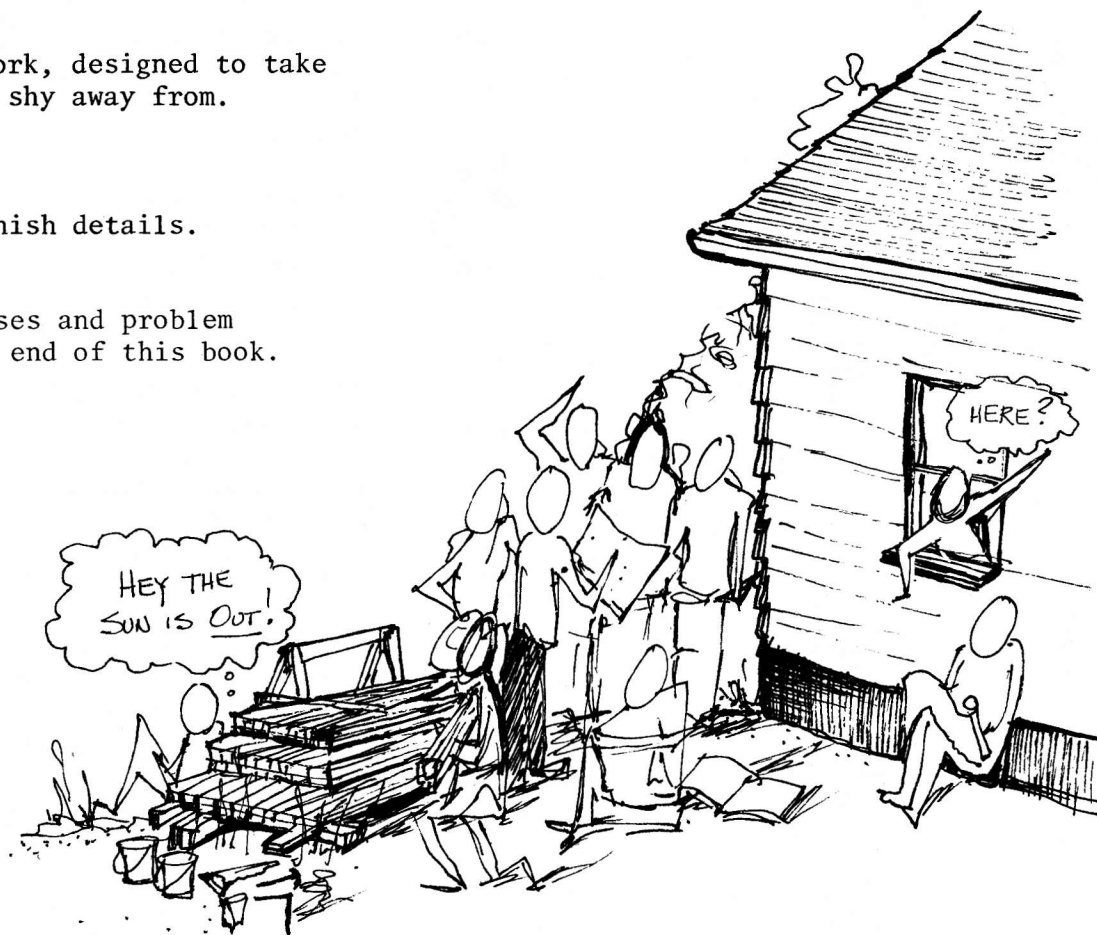
This section of the SOLAR GREENHOUSE WORKSHOP GUIDE follows the construction outline of the workshop format. The next pages detail the building process for a "standard" 10x16' solar greenhouse. If you've designed your own solar greenhouse for your specific needs, it may differ substantially from this basic design. Use the construction section for processes, problem solving and building techniques.

This section is divided into three parts:

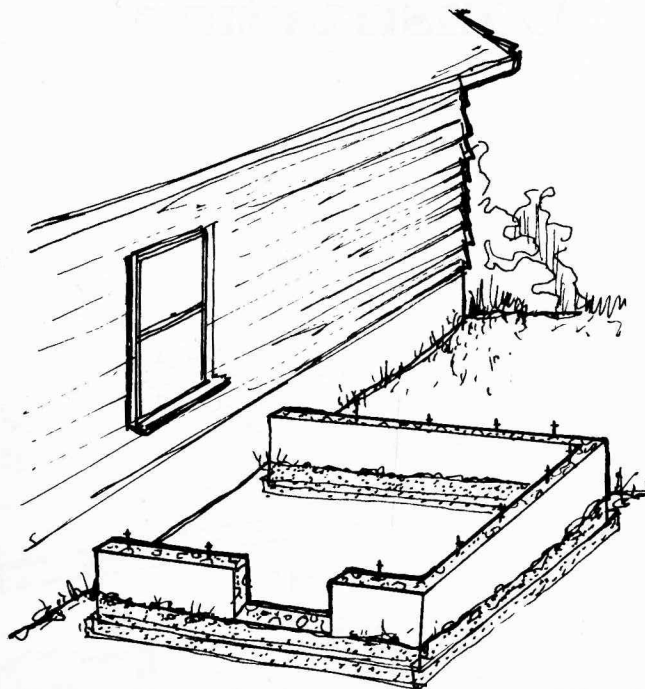
- (1) A detailed discussion of foundation work, designed to take the mystery out of a task many people shy away from.
- (2) Framing the greenhouse.
- (3) Glazing, sheathing, insulating and finish details.

For detailed references to building processes and problem solving, please see FURTHER READING at the end of this book.

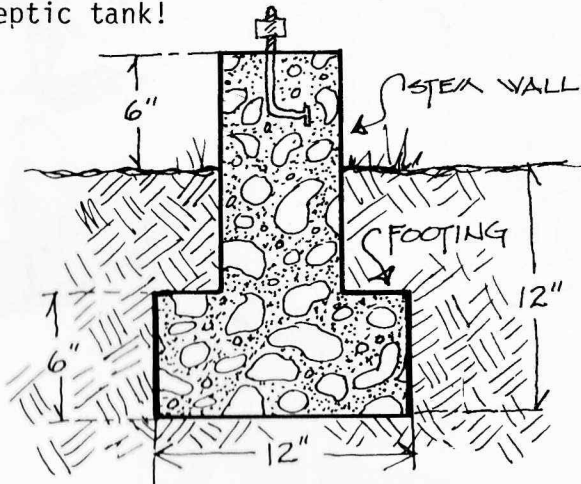
Good luck -- and enjoy yourself!



Introduction to Foundations



If your house is in a rural area without sewers, don't build on top of the septic tank!



The foundation of a building is the area of construction least familiar to many people, but is also of prime importance to the integrity and longevity of a building. If properly made, it will simplify the rest of the construction process. The foundation that we will be forming will meet the City of Seattle building code. Check with your building department for local variations.

The foundation for an attached greenhouse runs continuously around its perimeter, save for a section where the door goes. To meet local code, the foundation must begin 12" below grade (ground level) to protect it from frost heaving, and rest on undisturbed earth so that it won't settle. To protect the wooden structure in the building from micro-organisms in the soil, the STEM WALL must rise 6" above grade.

The most common shape for the foundation is the inverted "T". The base or FOOTING must be 12" wide and 6" thick. A 6" wide stem wall continues up from this another foot to 6" above grade.

Begin forming the foundation by determining its exact dimensions and its location in conjunction with the house. A level area is excavated adjacent to the house. The perimeter is marked out precisely with WORKING LINES and BATTERBOARDS at the corners. The perimeter is made perfectly square by adjusting its shape until its diagonals are of equal measure.

Overview

A trench roughly 18" wide and 12" deep is dug. Forms are built and set in place, with constant reference to the working lines to maintain size, square and level. The forms are then staked down, reinforced and braced. Concrete mixed by hand or delivered from a truck is poured, tamped down into the forms' corners, and SKREEDED (smoothed and leveled off). ANCHOR BOLTS are then set into the concrete at regular intervals for bolting down the SILL PLATES. The foundation is then left to cure for 2 or 3 days. The forms are removed, perimeter insulation set in, and the trenches backfilled. The foundation is then ready for framing.

The foundational process is not all THAT difficult and can be an enjoyable learning experience. Plan to do it in a comfortable length of time so that you CAN enjoy it.

Preparation and Working Lines

Begin by getting all of your materials together. As they are only in use a brief time, use scraps and what you have lying around. Check to see what lumber just purchased for the greenhouse can be used without cutting it up, as the concrete won't harm it for use later. It doesn't matter if you have a brace that's 8' long. Be creative with your use of materials for the forms.

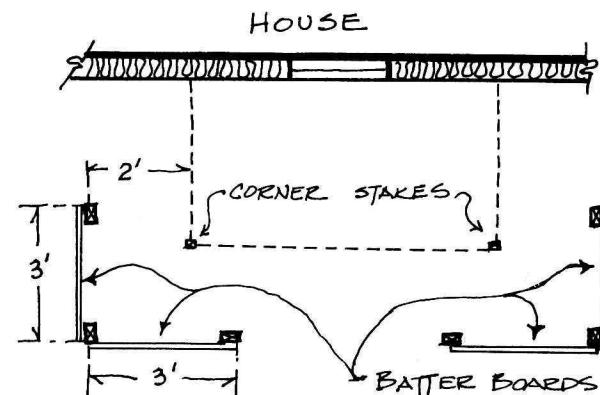
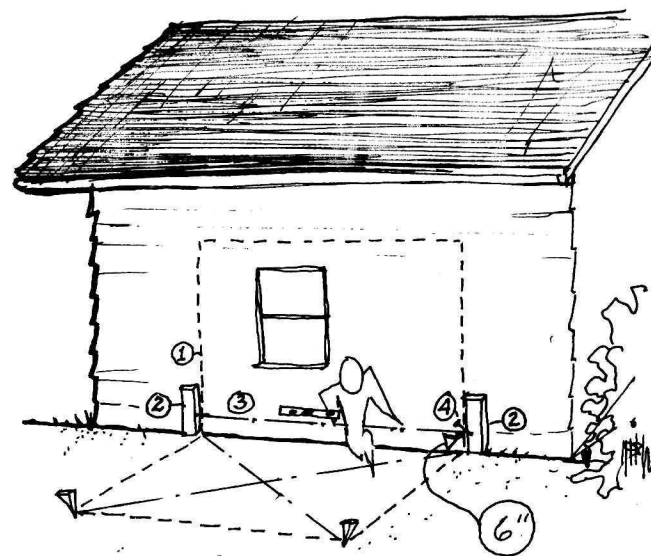
Since you may be using a lot of scraps, you might run out of gumption when you run out of what you estimated to be enough, especially late Sunday when you're just about finished. Plan well. Keep in mind that you'll be needing a lot of 3' stakes (1x4s, 2x2s and 2x4s) sharp at one end. You'll also need quite a bit of 1x2 material for form ties. Utility grade 1x2s can be bought inexpensively in bundles.

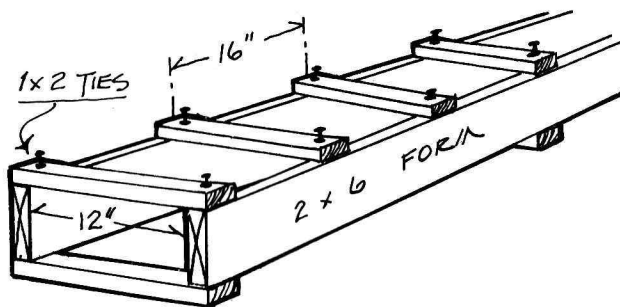
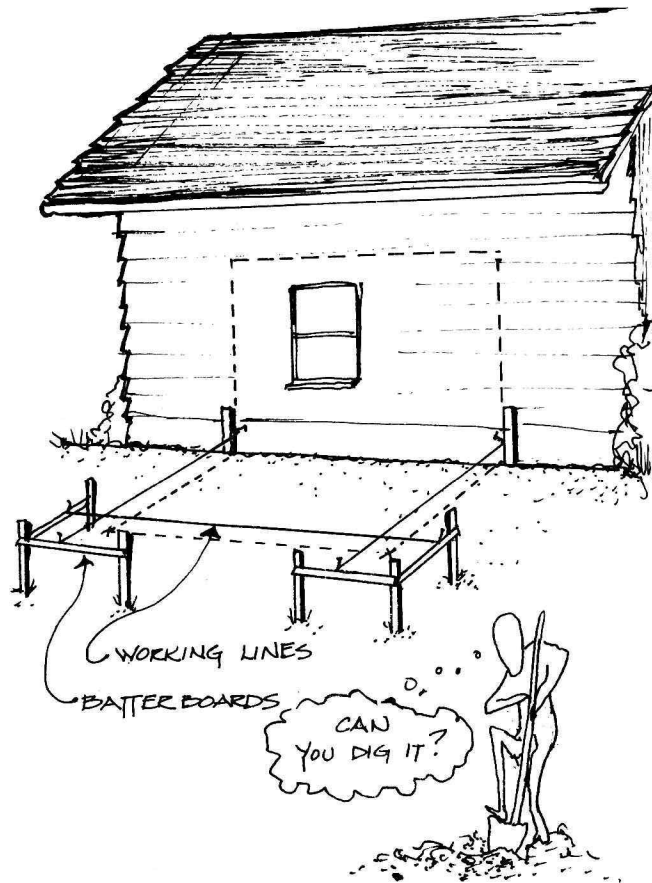
Locate the points on your house where the greenhouse will be attached. If the land slopes away from the house, excavate it and check it for level with a 2x4 and a spirit level. *The key to successful building is keeping square and level throughout.*

- ¹Mark the outside dimensions of the foundation onto the house.
- ²Nail a short 2x4 touching the outside of each mark so that 2x4s define the outside of the stem wall where it meets the house.
- ³Mark the 2x4s 6" above grade, making sure that these marks are level with each other. (Run a line between them and set a simple line level up to determine this.)
- ⁴Put a nail at each of these 2 points on the inner edge of the 2x4.

We'll mark out the perimeter of the foundation from these points. Using a carpenter's square and tape measure, come out 9'10" on each end and mark these points with a small corner stake. Adjust the stake until all four sides are the right length and the diagonals are equal in length.

Outside of these corners, we'll set up the batterboards. You'll need six stakes 36" long. At each corner, pound in three stakes 3' apart, forming a right angle so that they lie 2' outside of the foundation perimeter. They should be in good and sound, sticking up about a foot. Get some heavy nylon string for use in leveling and as the working lines for the batterboards.





Nail up the batterboards so that their tops are level with the 6" marks on the house by using a line level between the nails at the house and the stakes. The tops of the batterboards and the nails at the house should describe a plane that is perfectly level 6" off the ground.

Tie a line to one of the nails at the house and stretch it over the corner stake to the batterboard. When it's directly over the corner stake, mark the batterboard with a nail and tie it there. Do the same at the other end and for the front of the greenhouse.

Adjust the nails until the diagonals are perfect and the distances correct. When they are, the nails and their lines will be your constant reference points throughout the construction of the foundation. They mark the perimeter of the stem wall, its exact height, and will keep it square and dead level.

>>>These WORKING LINES can be removed while digging, but quickly slipped back on for a check. Check their positions occasionally in case someone trips on and shifts the batterboards.

Dig out a trench 13" deep and 18" wide so that it extends 6" to the outside and 12" inside of the working line. Clean it out so that you have a nice square trench with a level bottom that is exactly 19" below the line (the form lumber eats up an inch of space in the depth of the footing).

Foundation Forms

The construction of the foundational forms is divided into 2 parts:

- ¹The FOOTING form is constructed outside of the trench and lowered in.
- ²The STEM WALL form is added on to it while in the trench.

The footing form is built to look like a ladder with 2x6 sides held 12" apart by 1x2 form ties. Use the sill plates and 2x6s from the materials list for this. When cutting the lumber, check the outside dimensions of the footing forms -- they stick out further and so are longer than the stem wall.

Space the form ties 16" apart on the top and 48" apart underneath. Be sure to use doubleheaded 6d or 8d nails so the forms will come apart easily when taking them off.

Build the footing forms in three sections that can be lowered into the trench and fitted together (the inside corners can be cut to match at that point). Run a new line from the batterboards parallel to and 3" outside of the original. Sight down this line along the inside edge of the 2x6 to set the forms in the correct position, straight and square. Check to see that they are at the right depth. When you're satisfied with their position, pound stakes next to them every 4' on both sides and at joints -- then double check to see that they don't move. Level the form as you nail the stake to it. Stand back and admire your work -- you're almost done!

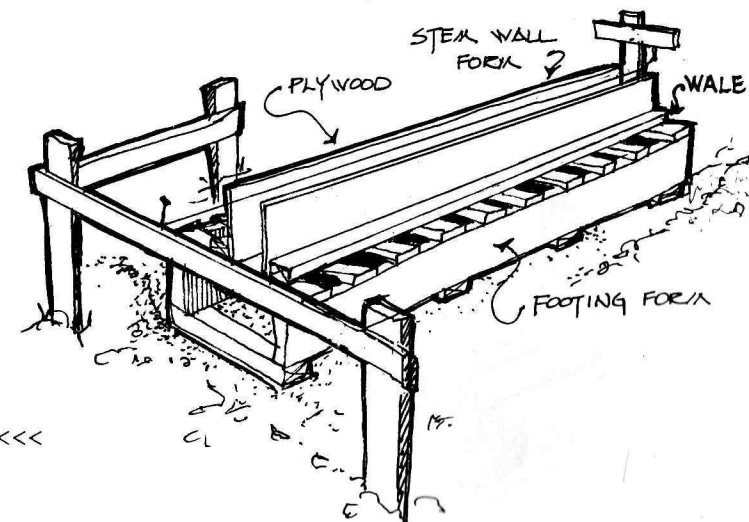
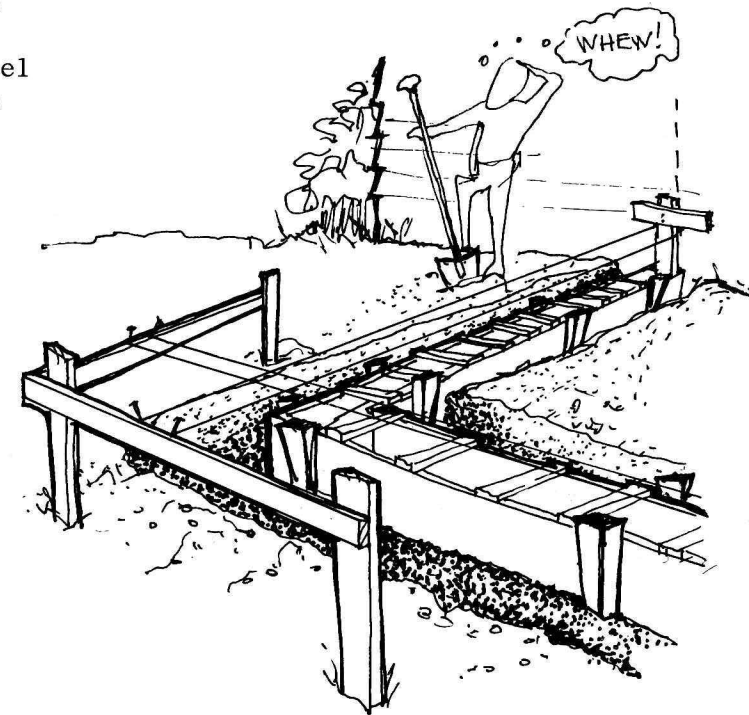
You now need to lay out the form for the stem wall. Go around the three footing forms and snap two parallel chalk lines (on the tops of the form ties) 3½" out from the center of the forms. Cut to the appropriate length and nail 2x4s along these lines so that there is a 7" wide channel running along the center of the form where the stem wall is going to begin.

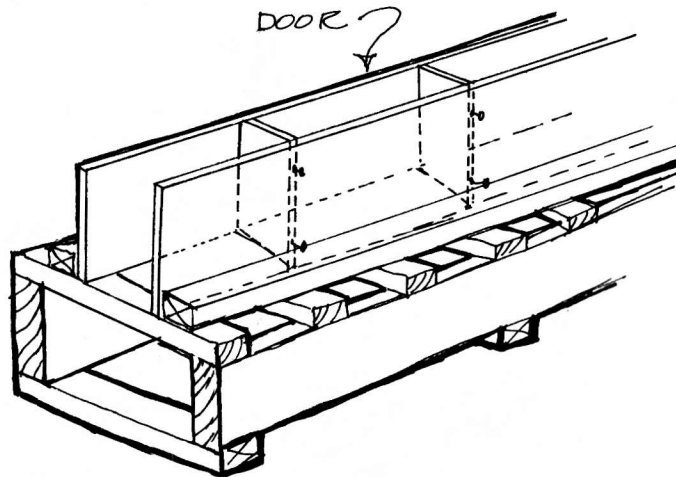
Cut 1' strips of ½" CDX plywood to the appropriate lengths for the side of the stem wall form. Nail these to the inside of the 2x4s so that there is now a 6" channel 1' high.

The stem wall form must be well reinforced and braced against the weight of the concrete. Don't cut up good 2x4s to do this. Use scrap pieces any length for bracing, including the new 8' ones for the greenhouse.

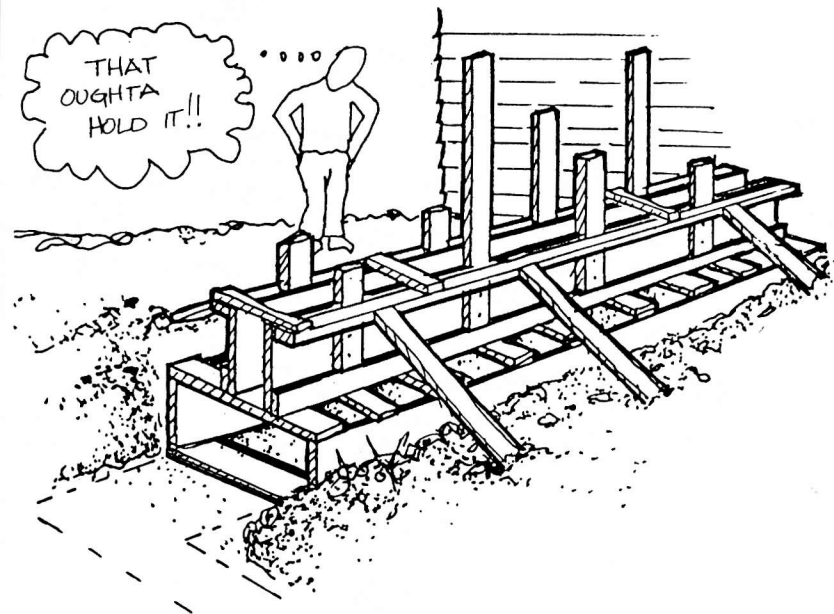
Start off by nailing vertical pieces on the outside of the form every 2-3'. Then nail a 2x4 on edge at the top around the outside perimeter. This is called a WALE and will keep the form from bowing. Now nail some form ties across the top of the form or wire the vertical posts together so that the form won't bow out when it's filled with concrete. Brace the outsides of the form every 3-4' with diagonal braces staked to the ground.

Check your forms for the last time with the working lines to see that they are still square, dimensional and level. The top of the plywood should be at the same level and describe the same <<<





Bolts have to be within one foot of all corners on both sides.



perimeter as the original working line. If it's square and level all around, you're home free. If your height is off any major amount, snap a chalk line along the inside of the plywood at the correct level and mark it with a few well-spaced finish nails to guide your trowel when screeding the concrete.

Check the plans for the location and dimensions of the gap to be left in the stem wall for the door. This is simply done by cutting some 6" strips of wood to the right lengths, wedging them into the form so that they describe the proper space, and nail through the form into the strips. The concrete is easily tamped under this form.

Mixing Concrete

Determine the volume within the form for ordering the pre-mixed concrete or for purchasing dry materials. A good basic dry mix is:

- 1 part cement
- 2 parts sand
- 4 parts $\frac{3}{4}$ " gravel
- $7\frac{1}{4}$ gallons water for each 94-lb. bag of portland cement

Pour the concrete into the forms slowly and tamp it down well to fill all the corners and gaps. Skreed it smooth on the top. Place in the $\frac{1}{2}$ "x6" anchor bolts at 4' centers, making sure that they don't come up where a greenhouse stud, mullion, or corner post will go. They should be $1\frac{3}{4}$ " in from the outside edge and stick out $2\frac{1}{2}$ " from the top of the concrete. Put the nuts on to protect the threads from concrete.

Let the concrete cure for 2 days before removing the forms. Apply 2" structural styrofoam (DowSM_{tm}) to the exterior of the foundation. Backfill the trench with the earth. Paint or sheath the styrofoam to protect it from sunlight.

You're done and ready to frame!

Alternative Foundations

For non-code situations, several other types of footings are possible. Pre-formed pier blocks with stirrups may be dug in and placed every 4' around the perimeter of the greenhouse and treated 4x4s set into the stirrups. The ensuing gap may be sealed up with structural styrofoam. The sill plate is then nailed directly onto the 4x4. Pressure-treated wood of the right dimension may be acceptable now in your area. Check with your building department.

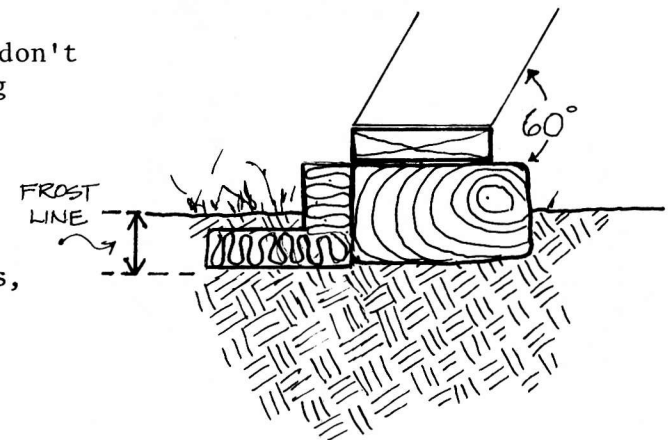
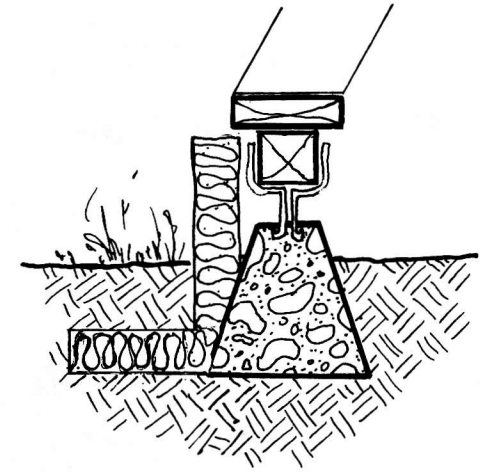
A successful and substantial foundation can come from setting railway ties into a shallow, level trench. Insulate their exterior to the bottom edge with structural styrofoam as shown in the sketch. This is an effective foundation for use in *arid* conditions. Again, the sill can be nailed right onto the railway ties. *Ties treated with creosote may harm plants. You need to wrap them with plastic.*

This overview of constructing a foundation will hopefully meet your needs for designing and constructing a quality greenhouse that will last many years. Although it's lengthy in description, don't be scared away. Your friends may have experience in form building and may be willing to offer advice or lend a hand. Doing the foundation yourself may save you hundreds of dollars and provide you the chance to learn a valuable skill.

For more detailed instructions on building alternative foundations, refer to FURTHER READING for construction guide books.

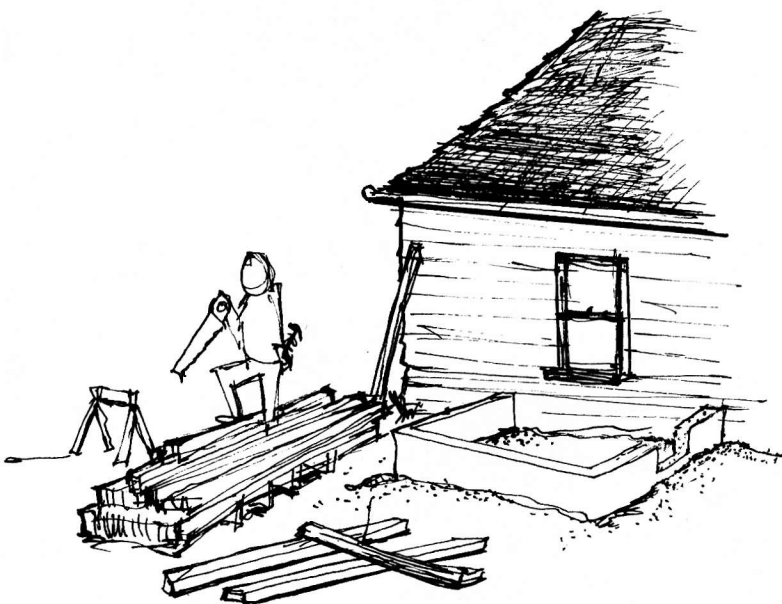
General Precaution

Foundations should be installed on undisturbed earth. This is important if future settling is to be avoided and the greenhouse is to have a long life. A further caution is that in digging beds, preparing for and insulating the foundation, you should be very careful to avoid digging beneath the foundation and undermining the bearing service.



Remember: The key to successful building is *keeping square and level!*

Framing the Greenhouse



The Lumber

The first step in purchasing lumber is to become aware of the grades and qualities of lumber available. The grade lumber you are after is STANDARD or COMMON #2 OR BETTER. It falls right in between UTILITY #'s 3 and 4 (which is inferior grade lumber with loose knots, slashes and often bad splits) and FINISH grade lumber (clear and vertical grain kiln-dried wood which is free from knots for use in cabinets and joining work).

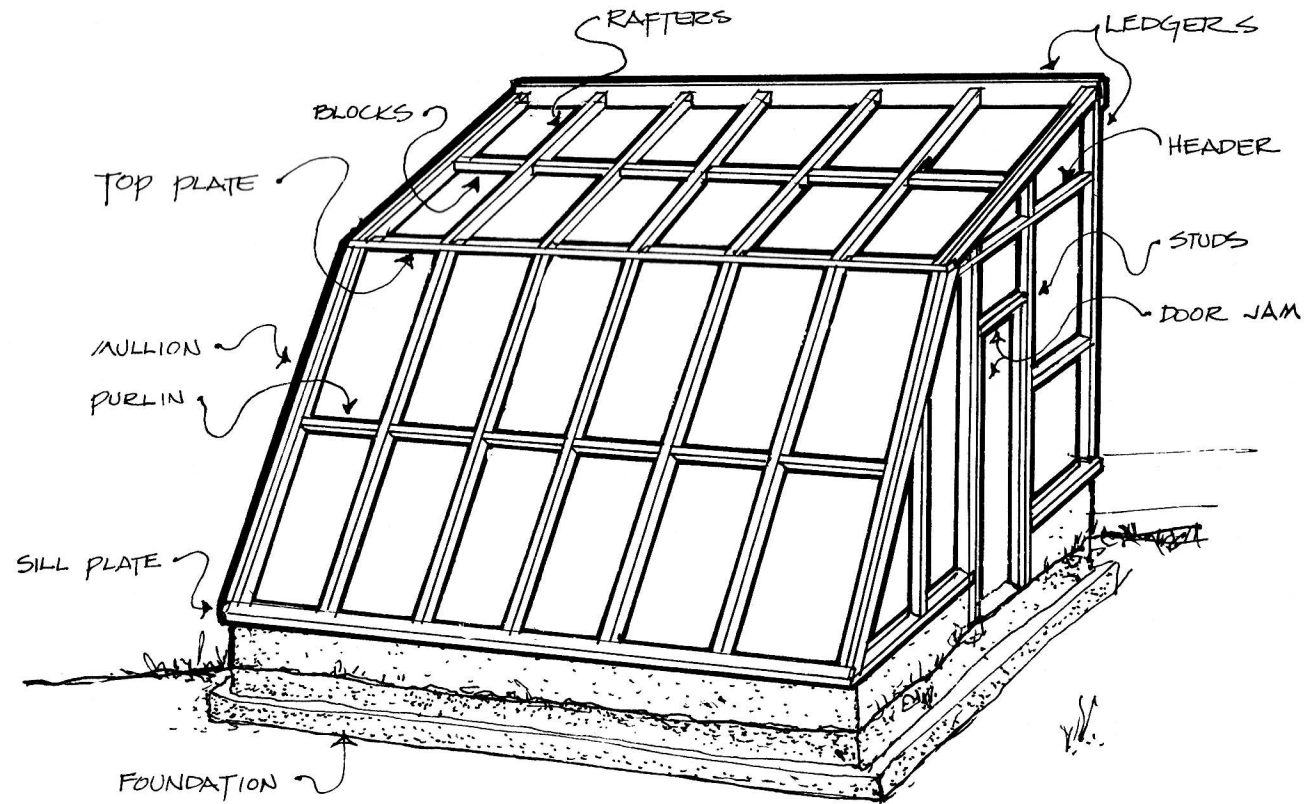
Standard #2 and better is sound lumber used in proper construction. It is graded to withstand the stresses described in the building code. This grade has in it randomly 25% #1, and 75% #2 lumber. Both of these are free from slash, large splits, and all knots are tight, unyielding even under force. Standard grade lumber is available kiln-dried (more expensive, but nice to work with) or green (in no way detrimental in the framing process).

While shopping around for prices, try to get a feel for the people at each lumber yard, as well as the quality of lumber they sell as representative of the grades. Although all grades are standardized, we have noticed marked differences in quality at different businesses. This difference seems to go hand-in-hand with the quality of the people and service. Unless you have a very reputable "discount" lumber yard near by, we have found that a local yard, even though more expensive, will offer excellent service (often with free advice when you're stuck), very high quality lumber and will let you pick through the piles for the better pieces.

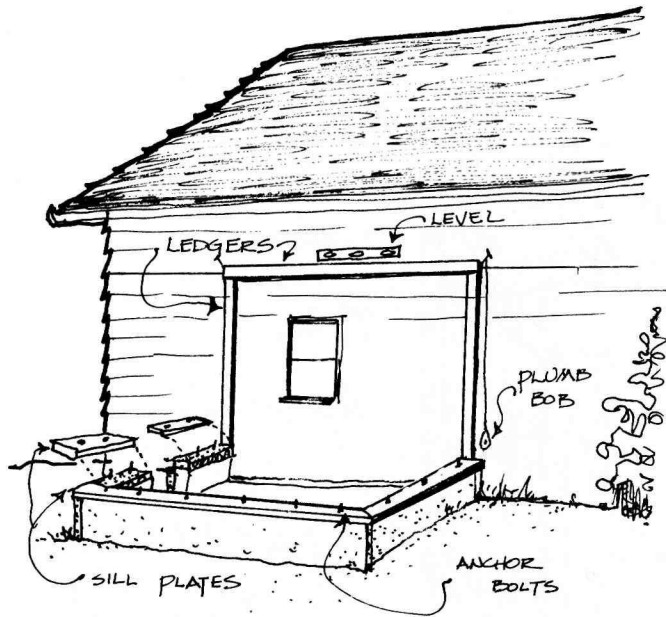
Large wholesalers who sell to professional carpenters have quality materials, but they may not want to deal in small quantities. You can bulk buy with friends to save money.

>>> Be careful when buying your lumber -- there's nothing worse than feeling taken and then having to work with inferior materials throughout the construction of your greenhouse.

Greenhouse Taxonomy



If you have problems finding wall studs, drive a nail in through the sheathing every inch until you find the solid studs.



If your home is brick, masonry, or concrete, use a masonry or star drill to make spaces for bolting the ledger plates to the house. Use special shields (lead or plastic) purchased with the bolts to anchor them into the masonry.

The first step in framing the greenhouse is laying out the geometry of the structure. The SILL PLATES and LEDGER PLATES make the connections between the entire greenhouse, its foundation and the house walls. If done square and true, they will give you the reference points for further determining correct dimensions, angles and true surfaces. (This is where your careful foundation work begins paying off!)

The sill plates should be *foundation grade cedar 2x6*, which will ensure longevity of the greenhouse. If this is unobtainable, be sure to get pressure-treated foundation material, or treat it yourself with copper naphthenate.

Cut the front sill to be the full length necessary for the glazing detail (16'5½"). This will overhang the stem wall 2" on each end and the front, covering the rigid styrofoam. Lay down a 3½" strip of fiberglass insulation around the entire perimeter of the foundation to form a proper seal between sill plate and foundation.

Mark the location of the anchor bolts, drill them and slip the sill over the bolts. Check to make sure that the sill is overhanging to the right dimensions and that it is SQUARE AND PARALLEL to the house (don't bolt it down yet). Measure the end wall plates right up to the house and cut them to length. Mark, drill, check for square, and when satisfied, bolt these down.

The ledger plates are of standard stock. On the wall of the house, mark the height to the top ledge plate directly above the outside edge of the sill. Drop a plumb bob down from this point and adjust until you are at the right height, directly true and straight above the sill. Mark this location at each end with a nail and run a chalk line down. The nail marks the upper outside corner of the horizontal ledger and the chalk line the outside edge of the vertical ones. The horizontal ledger is a 2x6, and the vertical ones are 2x4s.

>>> If the upper ledger is placed 1½" to 2" below the lap in your siding, flashing can be tucked under the siding later in construction after laying the fiberglass roof. A little pre-planning can save hours of work!

Determine where the studs are in the house wall behind your *horizontal* ledger and mark them. Cut the upper ledger to length, staple some fiberglass to the back (if the house wall is very uneven, it can be stuffed in later), start 5 or 6 nails, lift it into place and tack it on. Check it for level, tap it to adjust and when perfect, pound it home.

Measure the *vertical* plates and cut to length. Staple some fiberglass insulation to the back of them (unless you have shingles, in which case stuff it in later) and tack them in place when lined up with the chalk line. Check them for level just to be sure, and nail them up.

When you are satisfied that all is square and true, pre-drill and put in five $\frac{7}{16} \times 5\frac{1}{2}$ " lag screws and washers through the top ledger into the studs, and 3 lag screws and washers into each of the vertical plates. Caulk around the perimeter of the ledgers after the lag screws are in to insure an airtight seal.

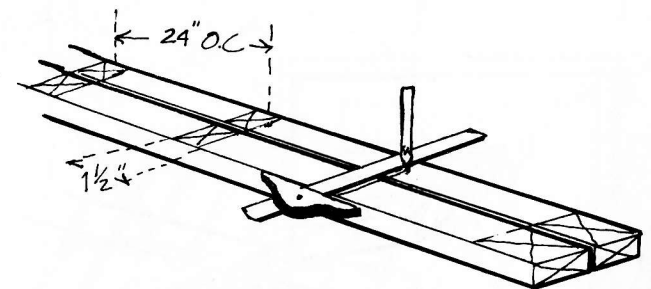
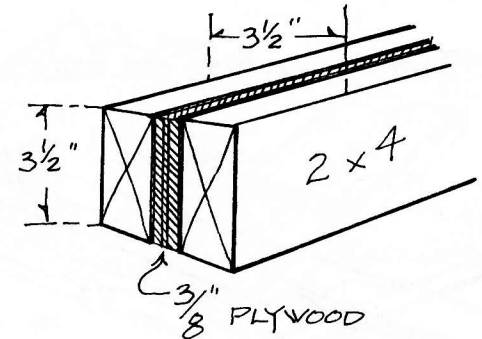
Now you're ready to start framing!

Framing the South Wall

Cut a 2x4 top plate to match the front sill (16'5½"). Remove the sill from the foundation and lay the top plate and the sill plate flat and side-by-side so they can be marked together to show the placement of the MULLIONS.

Looking at the plans, you see eleven mullions on the face. The corners are double-studded with a $\frac{3}{8}$ " strip of plywood sandwiched in between to bring it up to 3½" square.

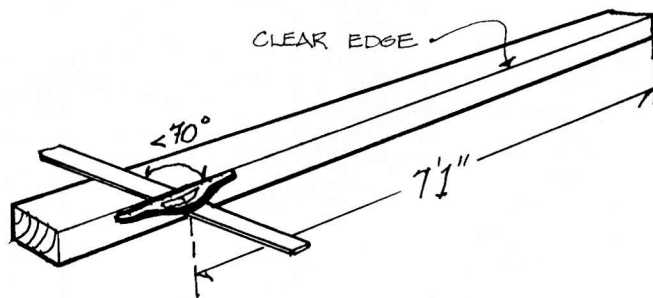
- {1} Mark 3½" in from each end with a combination square and scribe a line. This line is the inner edge of the first mullion of the glazing sequence.
- {2} Now begin scribing lines all the way to the other end at 24" (necessary for accepting the glass). These are also the "inner" edges of the mullions, so scribe another line 1½" back towards the original end and connect with an "X".



The mullions will sit on these marks top and bottom.
Double check to see that they are *exactly* 24" on center.

>>> If for some reason the foundation is not the right length to match the dimension sequence for the glazing detail, make up the entire mistake in one of the end sections. You can always trim a piece of glass to fit -- better than trimming them all!

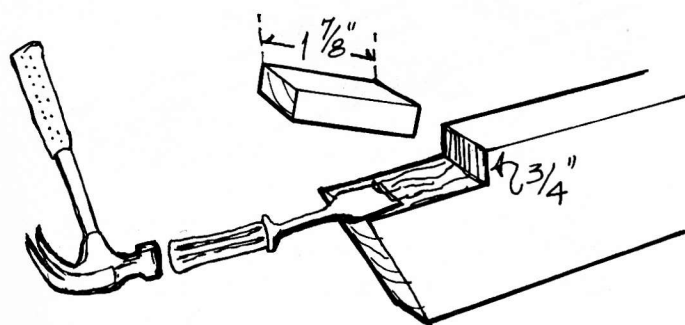
Measure twice, cut once!



Pick the 11 straightest 8' 2x4s you have, determine the worst end (these will be cut off) and the clearest edge (for seating the glass). Mark them all at 7'1" from the good end and scribe with a miter gauge set at 70°. DOUBLE CHECK and cut.

The bottom of the mullions must be notched to accept a 1x2 for the glazing detail. Mark 1/8" up from the angled end and 3/4" deep. The notching can be facilitated by laying the mullions side-by-side, marking them at once and making the 3/4" deep cut on all of them at once. With a wide chisel, chip out the bit of wood and clean out the notch to be parallel and flat with the face of the mullion. Check to see that a 1x2 fits snugly.

Cut four 3 1/2" wide strips of 3/8" plywood (save two of them for the rafters), sandwich them in between two sets of double 2x4s and trim.



Lay out the entire face of the greenhouse on a level piece of ground (directly in front of the greenhouse if possible), making it fairly square. The 2x6 will stick down a bit -- make sure that it is aligned so that the holes will be oriented in the proper direction for setting it back onto the foundation. Laying in the 1x2 will help make the mullions flush with the leading edge of the sill.

Starting at the corners, nail through the plates into the studs with 16d galvanized nails. DOUBLE CHECK YOUR MEASUREMENTS and nail in the 1x2.

Depending on how dry the 2x4s are, they will be between $1\frac{1}{2}$ " and $1\frac{9}{16}$ " wide. Measure the space between the mullions. Those 16ths can add up and badly bow a mullion.

Determine the correct spacing and cut out the PURLINS (called BLOCKING in an unglazed wall). Nail them in place midway up the face in an even line (nail through the mullion in one end and toenail the other). They should be *perfectly* flush with the faces of the mullions, making the mullions rigid, evenly spaced and perfectly straight.

Now, check for absolute square by measuring diagonals. When the diagonals are *exactly* even, tack a long 2x4 diagonally across the face and re-measure the diagonals. When you are perfectly satisfied, nail on the diagonal brace. This brace is going to hold the face square while you lift it onto the foundation and do a lot of adjusting.

Get a crowd together and lift the whole face on to the foundation, slipping it on to the anchor bolts. Lean it back until it is the proper length away from the wall (7'8" from the top of the ledger plate) and prop it up with 2x4s nailed to its sides.

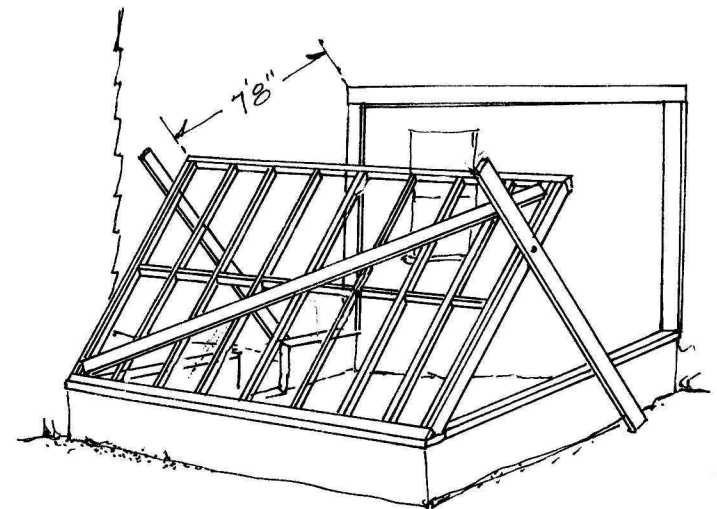
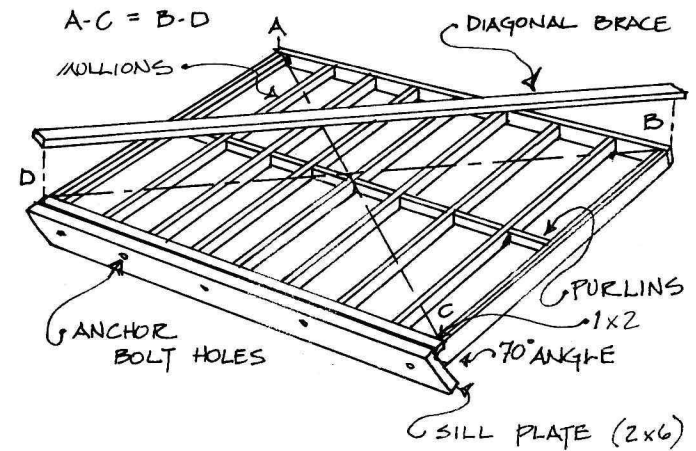
Remeasure, making sure that it is the proper distance from the ledger, parallel, and square with the house.

Hanging the Rafters

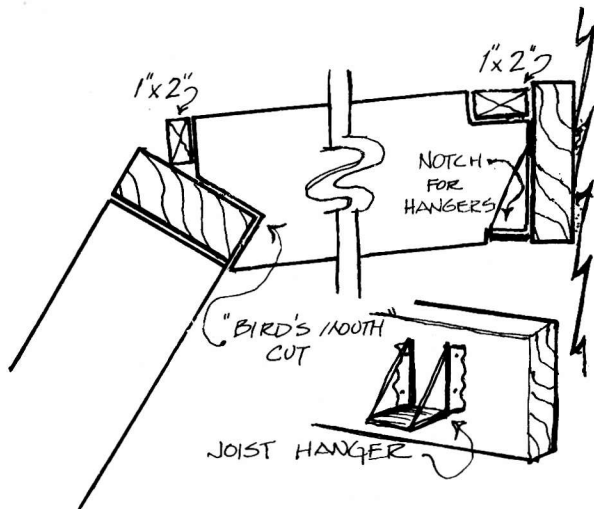
Measure the spacing for the joist rafters on the top ledger on 24" centers. The two end hangers will be 4x6 joist hangers, but begin measuring from the inside as on the south face.

These spacings need to be exact so that they will accept the corrugated fiberglass roofing later in construction. Mark the spacings for the rafters onto the top plate at the same centers.

Hold up an 8' 2x6 so that it spans between the ledger and the top plate. Mark it with a BIRD'S MOUTH at one end and with an angle and a notch at the other end. Then cut $\frac{3}{4}$ " off the pointed end so that a 1x2 can run flush with the top of the rafters the length of the greenhouse. Cut the 2x6 to shape. (See diagram, page 44)



<<<Determine while holding the rafter in place the vertical position of the joist hanger within the spacing. When satisfied, nail up the joist hangers.



The bird's mouth will fit onto the front wall. The notch is for seating into the joist hanger. At the point where the rafter meets the ledger, put in a notch for a 1x2 (as on the south face) to nail the fiberglass to. A little pre-planning now saves lots of time later. If the 2x6 you have cut fits, use it as a model for cutting out the rest of the rafters.

Make double corner rafters with plywood, like you did the face. Nail all of the rafters up. Put in horizontal BLOCKING, similar to the purlins, at the mid-points.

Framing End Walls

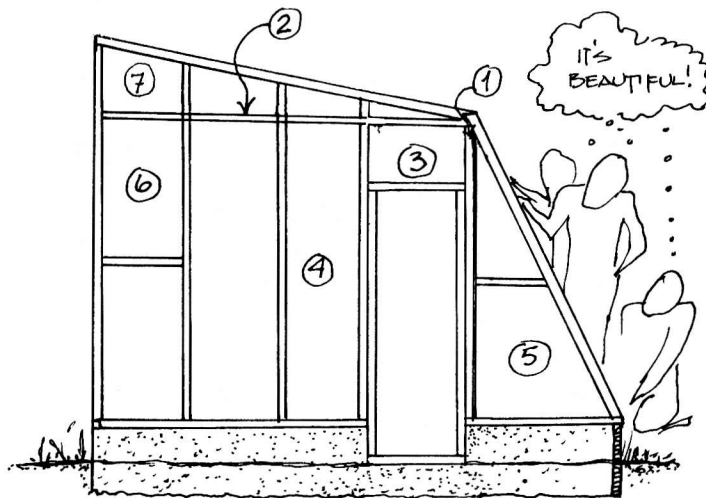
After removing the temporary supports, you may fill in the end walls to meet your specific design. We recommend making a wall that's half insulated and half clear glazing.

Drop a 2x4¹ from the birds mouth straight down to the sill, and lay a HEADER² straight across to the rear wall. Frame in the door using a double-studded frame with a header³. Next to the door, frame in a "window"⁴ with a stud at 24" center (to accept the glass). Extend the wall back with studs at 24" centers, checking them with a level as you go. Continue these studs up into the triangle with short blocks.

Define the opening for the low vent⁵ next to the door by putting in a horizontal spacer (the vent should be about 2'x2').

On the opposite wall, stud in the two windows on 24" centers. Continue the wall back with studs on 24" centers. Block in the upper triangle and define the opening for the large vent⁶ (about 2'x3') with a horizontal spacer.

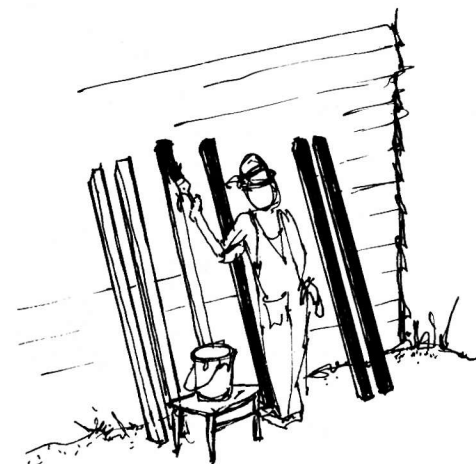
You're done! Give yourself and those around you a hug and pause to admire your work.



Painting/Staining the Frame

The mullions in your greenhouse will be getting more abuse from the rain and sprinkler cans than do the studs in your house. We recommend treating your lumber for longevity. Copper naphthenate is the best agent to use. Cuprinol wood stains come in a variety of colors and have a tin-based protective agent. Creosote and penta are detrimental to plants!

Depending on your timing and whether you paint or stain, your lumber may be treated previous to framing or after it's erected, then painted with an exterior grade enamel or latex paint. Another solution is to get a cuprinol wood stain to suit your color taste. This will need a day to dry, but using the stain as a protective agent may be done in one coat. Don't forget to paint or stain the 1x2 cap pieces for the glazing detail at this point.

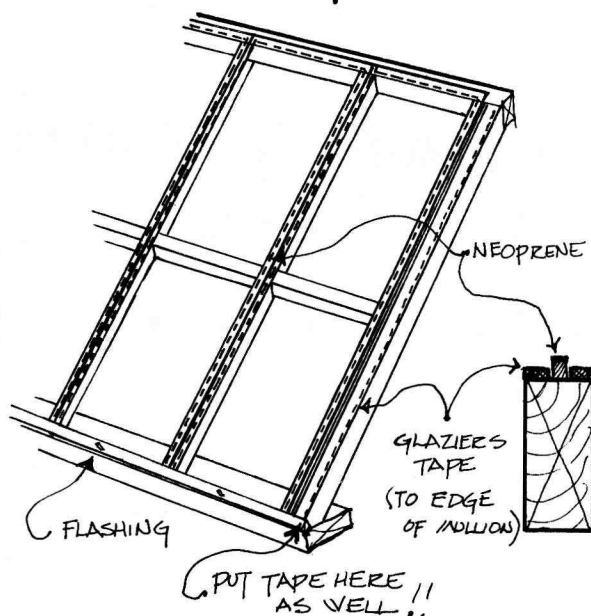
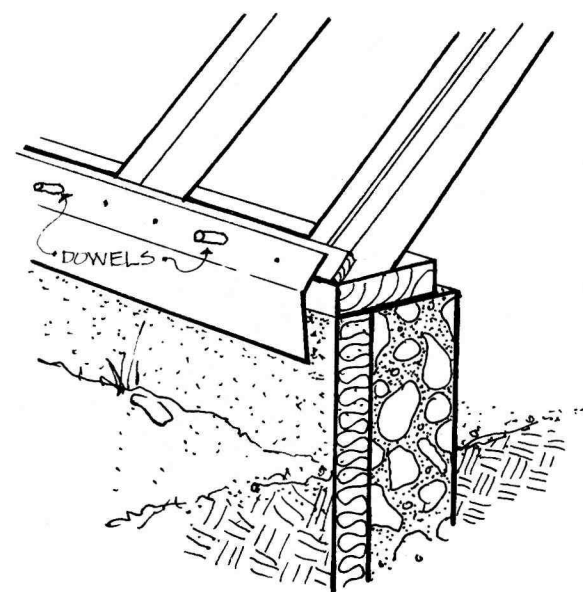


Now that the framing is completed, we will proceed with two jobs:

- (1) Glazing the greenhouse to make it as airtight and waterproof as possible.
- (2) Siding and insulating the end walls to help retain heat.

The sequence in placing a skin over the framework of a greenhouse proceeds *in the opposite direction of the flow of water* -- from the bottom to the top, with each surface overlapping like shingles.

Glazing, Insulating, Sheathing and Finish Details



Be sure to use neoprene SPONGE!

Overview

The south face of the greenhouse is glazed, with a strip of flashing tucked under the glass and hanging over the perimeter insulation. Tar paper is stapled to the exterior end walls and beveled siding is nailed up and trimmed to shape. The interior walls are insulated with $3\frac{1}{2}$ " fiberglass batts and 1" of structural styrofoam, then sheathed with plywood.

Corrugated strips of wood, "WIGGLE-BOARD," are attached to the roof rafters to accept the fiberglass roofing which overhangs the front face and end walls. Flashing is placed over the top of the fiberglass and tucked under the shingles or siding of the house. Doors and vents are constructed, hung and weatherstripped. Finally, all cracks and gaps are caulked and sealed.

The South Face

Cut a 6" strip of galvanized or aluminum FLASHING to the length of the greenhouse. Nail it onto and covering the 1x2 (with 6d or 8d nails) so that it hangs over the sill and the perimeter insulation. Through this flashing, $\frac{1}{2}$ " dowel pins are stuck into the 1x2 to hold up the glass.

Measure $\frac{3}{4}$ " down from the top of the 1x2 and midway between the mullions. Punch a hole through the flashing with a nail. Drill through the flashing and the 1x2 with a $\frac{1}{2}$ " metal bit, keeping perpendicular to the face of the greenhouse. Hammer a 2" long piece of $\frac{1}{2}$ " dowel in.

The $\frac{3}{8}$ " square NEOPRENE STRIP that helps space and seal the glass is stapled down the center faces of the mullions and along the center of the top plate. There should be $\frac{1}{2}$ " of mullion exposed on each side of the neoprene strip. Make sure the staples are in line with the length of the neoprene so they won't touch the glass! Carefully take the $\frac{3}{8}$ "-wide GLAZIER'S TAPE and lay it along the top and the two sides of each glazing section, next to the neoprene and even with the edges of the mullions. You're now ready to set in the $23\frac{1}{4}$ "x7' strips of glass. If all of the spacings are correct and square, there should be no difficulty.

While one person carefully carries the glass (wearing non-slippery leather gloves!) over to the greenhouse, another should be standing ready inside of the greenhouse. Set the glass onto the dowel peg and gently lean it towards the face. The person inside the greenhouse should be holding the glass out, while the person outside positions it perfectly inside of the neoprene strips, guiding it down onto the glaziers' tape. Try not to touch the glass to the glaziers' tape before it's positioned properly. *The tape sticks to the glass better than to the wood and makes a mess!*

The wooden CAP STRIPS are screwed snugly down over the glass, pressing it against the tape, squishing the neoprene to form an air-tight, waterproof seal. Cut to length and pre-drill all of the caps. The holes should be just large enough for the SQUARE-DRIVE SCREWS to push all the way into with a little force. The holes are spaced 9" apart, *but don't get them any closer than 4" from the ends of the caps as they then tend to curl the cap down and crack off the corners of the glass.*

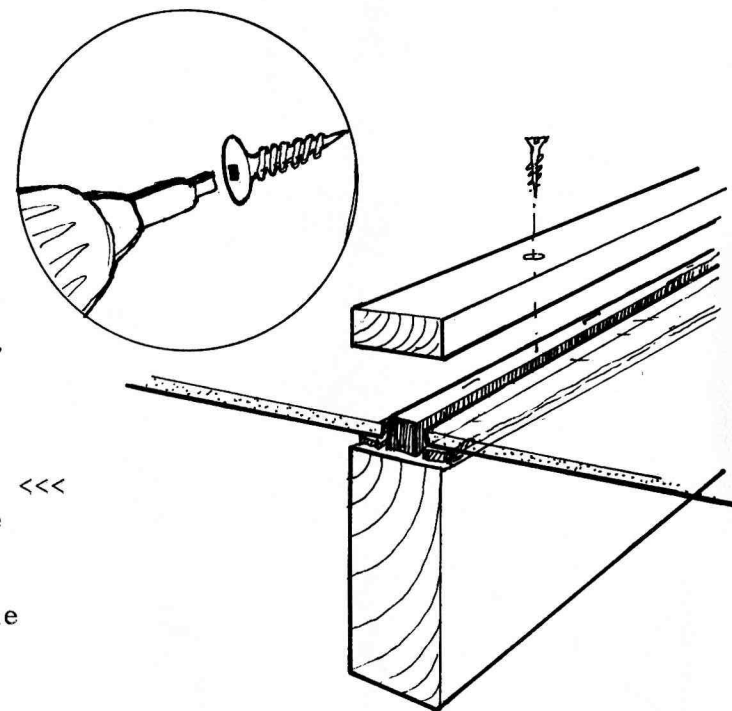
Make sure that the holes are exactly in the center of the caps <<< and perfectly straight. We want to screw straight down into the neoprene, not diagonally over into the glass!

The square-drive screws are a very positive screwing system. The drivers may be used in a screwdriver-type handle, in a bit and brace, or in an electric variable-speed drill. Regardless, a special sensitivity is required to know when to keep tightening the screw and when to stop. To gain a feeling of when to stop, watch for the glaziers' tape to just begin to squish out a little bit from between the glass and the mullion (easily visible from the interior of the greenhouse). That is as tight as the caps need to be.

Fasten the cap piece up over the top plate for the full length of the greenhouse first. Then put up the vertical caps. As long as the cap is kept directly over the mullion, there should be no problem. Leave the two end corner caps off until the siding is up. A 1x5 or 1x6 may be used there for caps to seal the glass and to cover the corner post and rough edges of the siding.

Putting up the glass is the quickest, most straightforward part of the building process. Be careful -- but don't be scared away!

Clear the area of workers, children, animals and other obstructions so that glass handlers can safely transport sheets of glass.

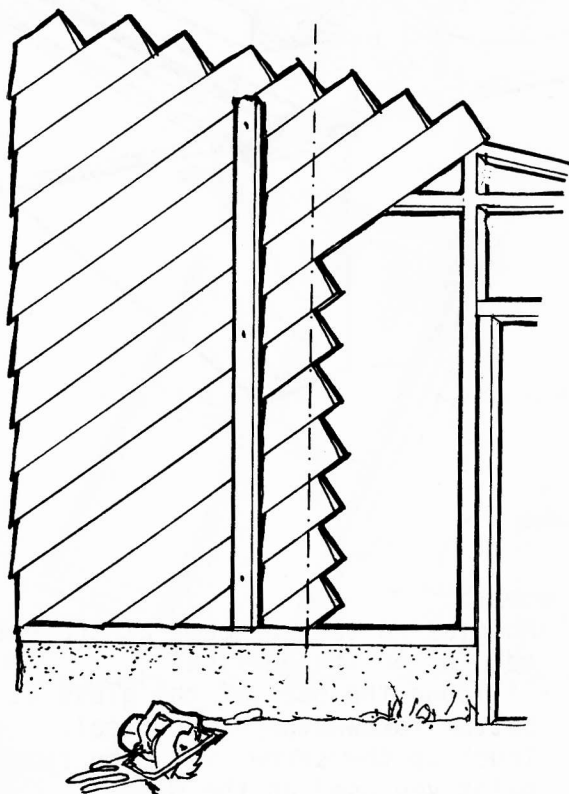


NOTE:

- No glazing tape or caps at the bottom edge or on the purlins!
- Silicone the back of the glass at bottom for weather-tight seal.
- Touch up the screws with the same paint you used on the wood.



A board the same width as the exposed face is an excellent guide.



The End Walls

The end walls should be sided before the fiberglass is up on the roof for convenience in placing and trimming to shape. Tar paper (15# roofing felt) is stapled to the exterior of the studs and the siding nailed directly onto that. It is sometimes helpful to snap a chalk line where the studs are behind the roofing felt to aid in nailing. Utility grade cedar siding is very inexpensive if you can find some.

Place the siding either horizontally or diagonally, with the bevels overlapping an inch. A board the same width as the exposed face is a speedy guide for placing the siding so that the overlap doesn't have to be measured each time.

When trimming the edge of the siding once it's up, a guiding board nailed parallel to the cut (spaced to align the saw blade correctly) to run a skill saw against will leave a straight and perfect line.

The inside of the end walls are just as simple:

Insulate with 3½" fiberglass batt insulation in between the studs and with 1" structural styrofoam tacked over this onto the surface of the studs. This brings the insulating value of the wall close to R-19. Snap a chalk line where the studs are. A good vapor barrier is essential in a greenhouse environment. If the styrofoam is installed with care, it will serve as a vapor barrier. Alternatively, 6 mil vinyl carefully installed to avoid holes and tears will function as a vapor barrier. Plywood nailed up over this should be painted or stained.

>>> When setting the glass on the end walls, make sure that the siding hasn't hung over the face of the mullion even a small amount. This can displace the cap enough to place the screws directly over the glass!

The Roof

The corrugated fiberglass on the roof should be installed to be just as air-tight and waterproof as the south face glazing. Use silicone caulk around the edges of the roof and on the corrugation overlaps to accomplish this. If you combine this technique with hanging the fiberglass over the end walls one corrugation and overhanging the front face, it will save having to put up flashing.

A quick but dirty job starts off the roof:

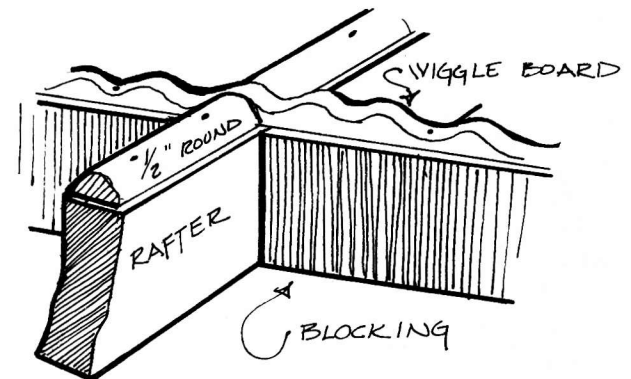
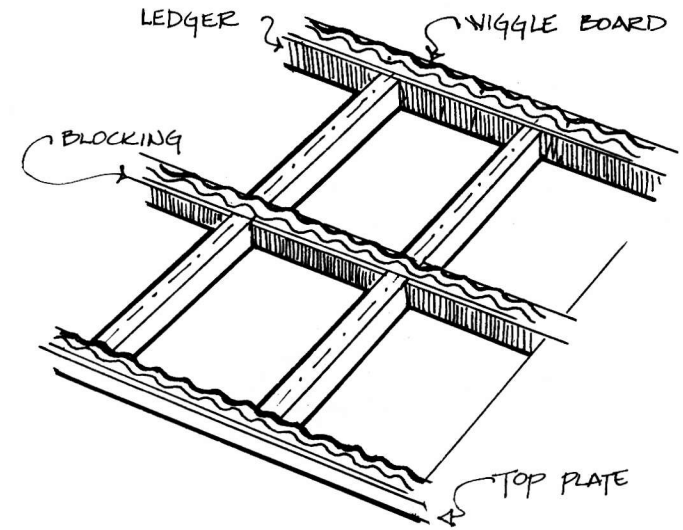
You must go to the top ledger at the house connection and pry up the siding or shakes. You're going to slip flashing under them, so remove any nails that could block this. If your greenhouse is tucked right up under your eaves, you may be able to leave off this flashing.

Wiggle-board is now placed the length of the greenhouse along the upper and middle horizontal blocking, and along the top plate at the lower end of the roof. HALF-ROUND MOLDING will run along the tops of the rafters to support the fiberglass roofing. *The wiggle-board must lie so that the tops of the wiggle-board hills are in line with the rafters.*

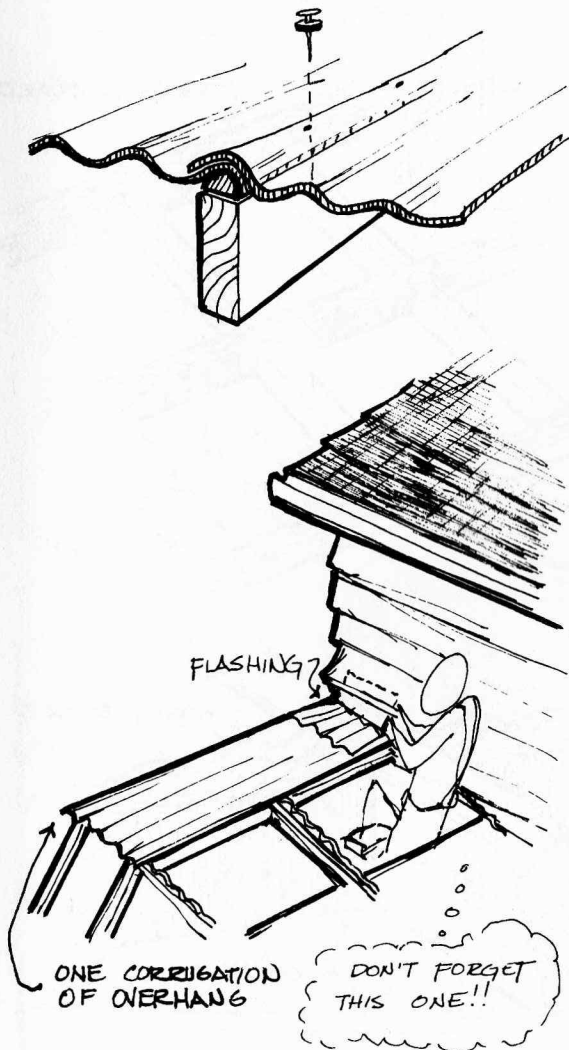
Run a bead of caulk along the back of a strip of wiggle-board and place it on the upper horizontal blocking so it is lined up correctly with hills on top of rafters. Nail it down with finish nails. Run some caulk along the back of two more pieces and lay them down on the middle blocking and the top plate so that they are in line with the first piece. *Don't nail these!*

Put a strip of fiberglass on top of these and square it up with the roof. Adjust the two lower pieces of wiggle-board to sit properly under the fiberglass and mark their position. Take down the roofing and nail up these two pieces of wiggle-board. Their hilltops should still be in line with the rafters!

Caulk and nail up the rest of the wiggle-board running from these first three pieces. Cut the half-round pieces to fit in between the wiggle-board and to sit on top of the rafters. *Be sure to caulk under the strips on the two outside edges, then nail it all down.*



Be sure to use greenhouse quality fiberglass roofing that has been specially treated to reduce ultra-violet degradation. Otherwise the fiberglass will quickly lose its transparency.



To finish the roofing, narrow strips (6"x8") may need to be cut, depending on the width of the greenhouse and the siding used, to overhang the end walls.

Now you are ready to lay up the fiberglass. Run a bead of silicone caulk on the tops of the perimeter strips of wiggle-board and half-round where the first piece of fiberglass is going. Drop it straight down onto the silicone without sliding it. Make sure it overhangs the endwalls one corrugation and over the front 2"-6". Nail it down on 6" centers into the half-round with washnails and on the hilltop of every third corrugation. If the wood splits or the fiberglass cracks, *you may have to pre-drill these holes.* Weatherstrip well!

Now, slip the flat side of the end wall flashing underneath the house's siding. Fit it into place onto the section of fiberglass. Silicone the overlap corrugation on the length of fiberglass. Caulk also the top and bottom wiggle-boards and set in the next sheet of fiberglass (it should overlap one corrugation). Nail down (and pre-drill) as before. Continue in this pattern along the entire length of the roof.

The Door and Vents

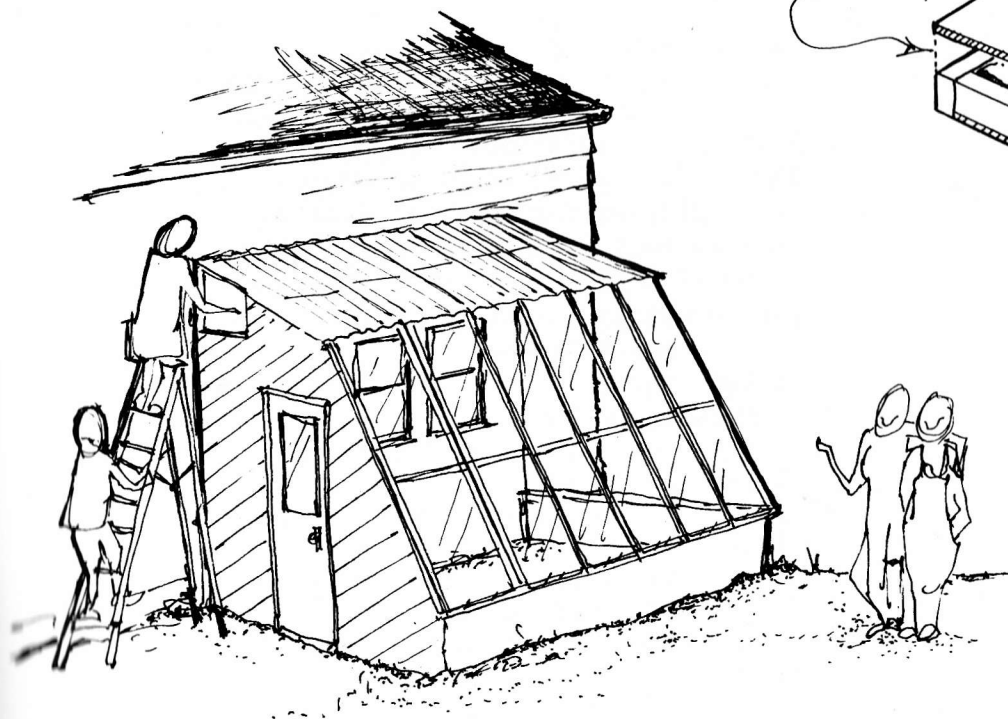
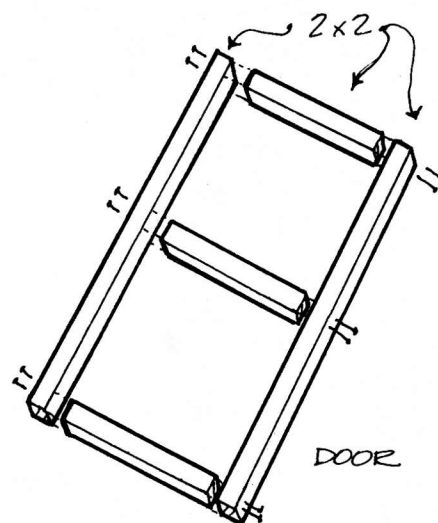
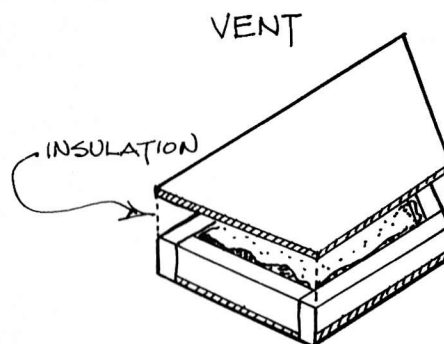
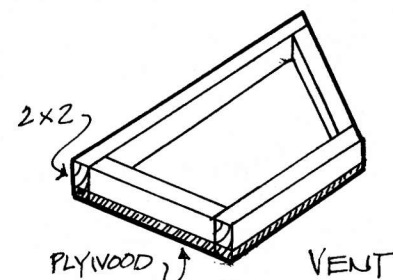
The doors and vents presented here are designed to be made as simply and efficiently as possible. The vents are made of 2x2s cut to the dimensions blocked out in the end wall frame, with sections of CDX plywood shaped to fit. Nail and glue the 2x2s to one of the plywood shapes and check it in the opening for ease of fit. Stuff it with styrofoam or fiberglass and glue and nail the front piece of plywood on.

Set the vents in place as they will eventually hang, marking their inside perimeter onto the framework. Nail doorstop molding along this line and hinge the vents so that they open out. A simple hook-and-eye will hold them open or shut.

If you are unable to find a nice door lying about, a simple and rigid design is for a door glazed on the upper half and insulated below. Size 2x2s (2x4s make for a sturdier door, but are harder to work with) for a fairly snug fit within the door frame. Glue and nail the corners of the 2x2s and the mid-brace together. A piece of plywood glued and nailed on will keep the door square and rigid. Tack the plywood on and slip the door into the frame, adjusting until a perfect fit is obtained. Nail the plywood tight. Insulate the hollow and apply the plywood face sheet. The glass may be "stopped-in" with molding and glazier's tape.

Nail in the doorstop molding, hang the door, and weatherstrip well. Weatherproof thresholds may be purchased inexpensively and make a very good weather seal at the bottom of the door. Put in some hooks-and-eyes, a handle, and stand back. Look around the greenhouse very carefully. Any cracks, gaps, or poorly joined surfaces should be well-sealed with caulk and, if large enough, stuffed with a little insulation.

YOU DID IT!! Stand back and admire the greenhouse and yourself -- and get ready for a little warmth and homegrown food!



Materials

Foundation

36 ft³ or 1½ yards concrete

Forms (if greenhouse materials are not used):

4 4'x8' ½" CDX plywood
 50' 1x2s
 6 36" sharpened stakes (batterboards)
 72' 2x4s (1' and longer)
 60 1' to 3' stakes
 30 longer braces
 3 lbs. 8d duplex nails
 finish nails
 string

Lumber

5 6' 1x2
 12 8' 1x2
 4 10' 1x2
 20' 2x2
 2 12' 1x4
 1 16' 1x4
 3 14' 2x4
 20 16' 2x4
 1 20' 2x4
 1 20' 2x6
 6 16' 2x6
 2 10' 2x6 foundation grade cedar
 1 18' 2x6 foundation grade cedar
 13 4' wobbleboard
 9 8' half-round for corrugated fiberglass
 3 4'x8' 3/8" CDX plywood
 130ft² 7/8"x8" utility grade bevel cedar siding
 36' ½" cove or quarter round moulding
 40' 1 3/8"x½" door stop moulding
 lumber for planting boxes

Other Materials

125ft² tar paper
 70ft² 3½" fiberglass insulation
 5 1" 2'x8' blue structural styrofoam
 5 2" 2'x8' blue structural styrofoam
 1 ½"x36" doweling
 7 2x6 joist hangers
 2 4x6 joist hangers
 1 3' door threshold
 (aluminum extrusion and vinyl)
 18' 6" galvanized or aluminum flashing
 200 aluminum fiberglass nails with washers
 8 2'x8' *greenhouse quality*
 corrugated fiberglass (128ft²)
 8 28" pieces endwall flashing
 (if necessary)
 3 tubes caulk
 4 tubes silicone caulk
 12 5½"x5/16" lag screws and washers
 11 23¼"x84" double strength glass
 200' 1/8"x3/8" butyl tape
 130' 3/8"x3/8" neoprene *sponge*
 glazing for door, if desired
 2 gallons copper naphthenate-based stain or
 paint with copper naphthenate preservative
 175 #10x2" flathead square-drive screws
 and 2 drivers
 1 set 3½" to 4" butt hinges for door
 2 sets 2½" to 3" butt hinges for vents
 3 pulls or handles for door and vents
 3 sets hooks and eyes
 34' "spring metal" weatherstrip
 10lb. 16d galvanized nails
 5 lb. 8d galvanized nails
 2 lb. 8d finish nails
 1 lb. small finish nails
 2 lb. siding nails

A Windowbox Greenhouse

A windowbox greenhouse can be placed over any southfacing window that has a clear view of the sun throughout most of the year. If its south face is larger than the window, it increases the usable amount of sunlight received and converts it to heat. It also reduces the amount of heat lost from the inner window by acting as a storm window. The excess heat created in the greenhouse space is vented into the house through the window or through special vents made in the wall at the top and bottom of the greenhouse. A small fan may also be used in some situations to increase the flow of warm air.

There are many ways to design a windowbox greenhouse. One of the simplest is to use a triangular cross section as shown in Figure 1. Because of its inherent strength and rigidity, we have chosen this design to give detailed instructions for building a windowbox. A narrower profile can be obtained by used in a vertical face design like that shown in Figure 2. This style can be used to give more solar aperture without creating a narrow angle at the top of the greenhouse. This cross-sectional structure is not as stable as the triangle-style and will require reinforcements to maintain the angles.

Both of these designs are cantilevers because they project horizontally from the wall but are anchored at only one end. Cantilevers come in several varieties -- the basic ones are compression cantilevers, balance beam cantilevers, sheer wall cantilevers and tension cantilevers. Compression cantilevers are supported by a bracket as shown in Figure 3. Both of the designs shown above are compression cantilevers. This style is applicable to add-on windowbox greenhouse projections. For a basic education in cantilevers and their applications, see "Cantilever" in *Sunset Magazine*, March 1979, pp.94-99.

The size of the windowbox greenhouse built with the following instructions is shown in Figure 5. If you want a different sized windowbox, follow the discussion of windowbox dimensions at the close of this chapter. Size alterations will modify the materials list somewhat.

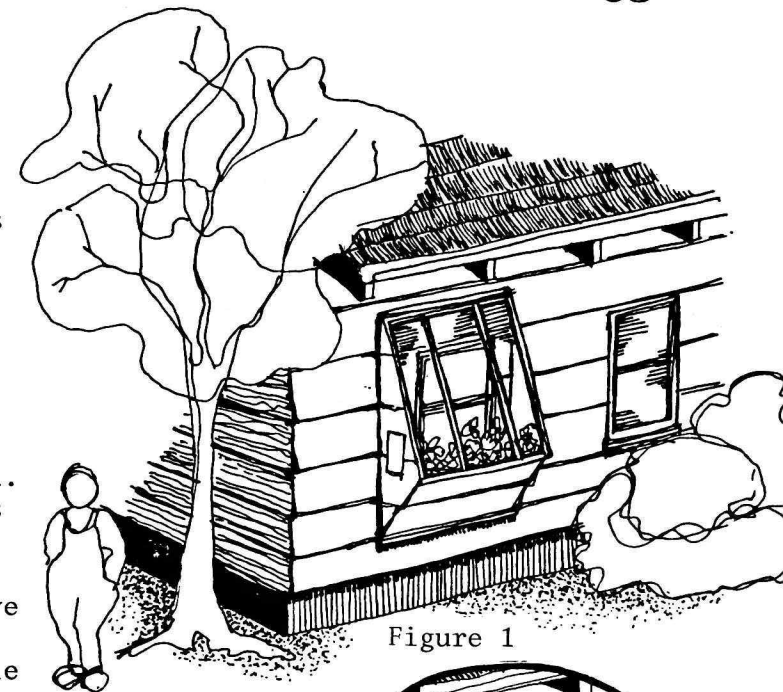


Figure 1

drawing by Susan Gross

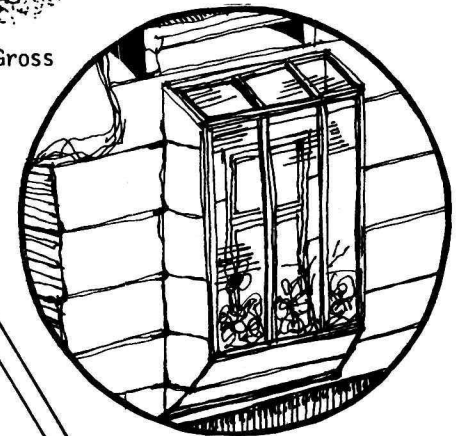


Figure 2

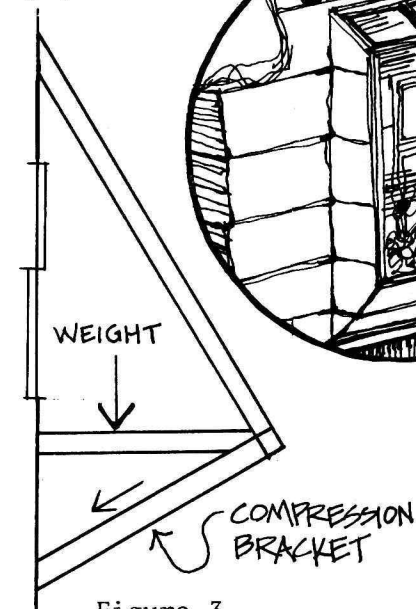
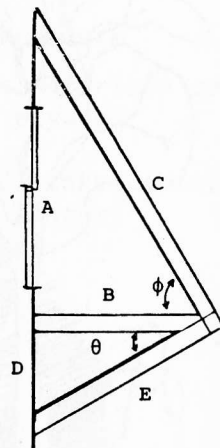
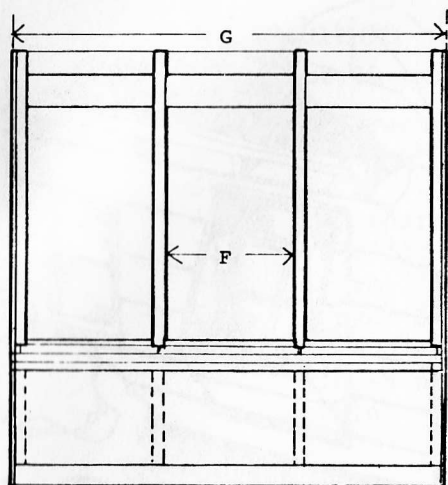


Figure 3



Figures 4 and 5

$A = 66\frac{1}{4}"$	$F = 29"$
$B = 38\frac{1}{4}"$	$G = 89\frac{1}{2}"$
$C = 76\frac{1}{2}"$	$\theta = 30^\circ$
$D = 22"$	$\phi = 60^\circ$
$E = 44\frac{1}{8}"$	

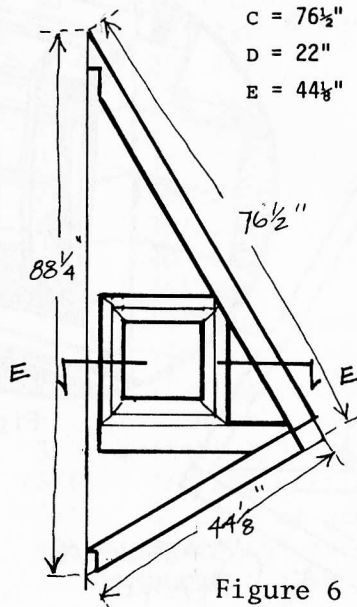


Figure 6

Step 1: Place Ledger Plates

Determine where the top line of the windowbox will be on the side of the house. Using a level, draw a line across the house at that level. Now, draw a second line 5" below the first. This second line will make the top edge of the top header. The header is a 2x6 and runs the length of the windowbox *minus* 2" ($81\frac{1}{2}"$ total).

Now draw another line at $A + D$ below the top line ($66\frac{1}{4}" + 22" = 88\frac{1}{4}"$). The bottom ledger should be placed so that its top edge is 4" above this line. A third 2x4 ledger plate should be placed so that its top edge is $4\frac{1}{2}"$ below the height of the planter bed that is located distance D ($22"$) above the bottom ledger line. At each end, a vertical side ledger should be installed. This may be a 2x4 nailed to the siding.

The top, middle and bottom ledger plates should be lag-screwed to the wall studs with $4\frac{1}{2}" \times \frac{1}{4}"$ (minimum) lag screws. Drill a hole at each stud and install a 1" round washer on each lag screw shaft. There should be 6 to 8 lag screws for each plate.

Paint the lumber to be used with copper naphthenate wood preservative or some high quality exterior paint. This step is much more difficult if done later. Without protection, water damage and rot could appear under the conditions of plant growth and heavy usage and may soon require major repairs.

Step 2: Cut Side Panels

Side panels are constructed from plywood and each includes an 18" square vent door that opens out. The side panels will set the form for the rest of the structure and should accurately follow the geometry given in Figure 6 or computed from the directions on page 68. Begin by cutting two pieces of plywood to this shape. Try to cut both pieces out of one standard sheet of plywood.

Mark the location of the top of the planting bed. Using this line as the bottom, draw an 18" square with the side that will be toward the house located $1\frac{1}{2}"$ from the edge (to account for the thickness of the side ledger plate).

Use a jig saw to cut out the vent door hole. (Save the piece you cut out to make the door in Step 4.) Install a frame nailed to the plywood around the edge of the door opening. Use panel adhesive to secure it firmly. The top and sides will be 18"-long 2x2s. The top and bottom will be a 22" long 2x2. Repeat for the other side panel.

Step 3: Frame Side Panels

Cut and notch the 2x4s for the leading edges of the side panels as described in Step 5. Then apply panel adhesive and nail them in place. These 2x4s should stop $3\frac{1}{2}$ " short of the lead corner to allow a 4x4 crosspiece to be installed in Step 7. The top one will be 73", the bottom one $40\frac{5}{8}$ ". Repeat this step for the other side panel, making sure you have a *right* and a *left* panel. The framing will be on the inside of the finished windowbox. Glue 1" styrofoam to the plywood walls.

OPTION: If you want to cover the inside surface of the windowbox walls, do so now.

Step 4: Hang Vent Doors

The vent doors should be hung to open out. The plywood pieces cut from the side panels should be used to make the vent doors. Frame the door pieces (remember to use panel adhesive) with 2x2s around all four sides and glue a 1" thick sheet of styrofoam insulation in place. Nail a frame made of scrap from cap pieces around the edge of the door opening as shown in Figure 7, set to allow a 1x2 stop for the door to close against. Mount the hinges and hang the door to swing *out*.

Step 5: Cut Mullions and Supports

Mullions are cut with notches as shown in Figure 8. The outside length of the mullion is dimension C *minus* $3\frac{1}{2}$ " (see Figure 5). That is, if C is $76\frac{1}{2}$ ", the mullion will be 73". Each top mullion is made identical to the others.

Cut the supports with notches as shown in Figure 9. Their length should be E (from Figure 5) *minus* $3\frac{1}{2}$ " ($40\frac{5}{8}$ "). Again, make them identical to one another. Cut a 4x4 timber to the outside dimensions of the windowbox *minus* 1". Cut crosspieces to length B ($38\frac{1}{4}$ ") and notch to receive 4x4 as shown in Figure 10.

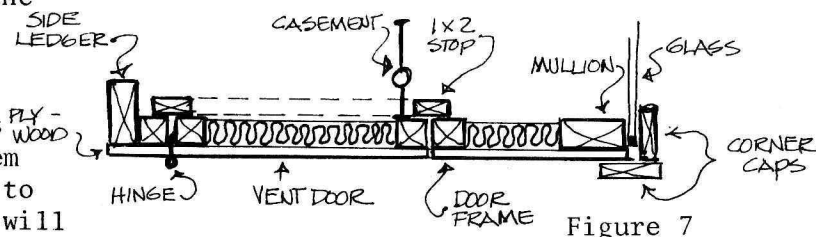


Figure 7

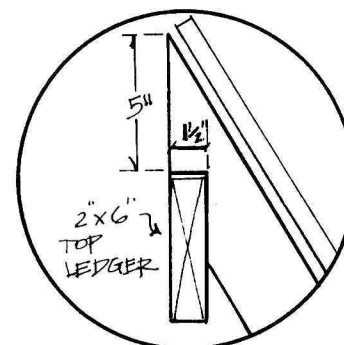


Figure 8

drawing by Susan Gross

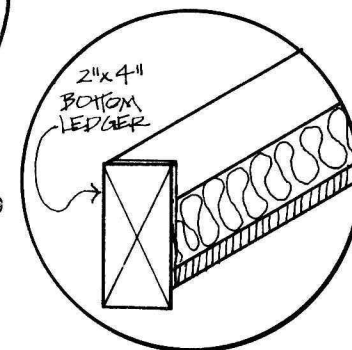


Figure 9

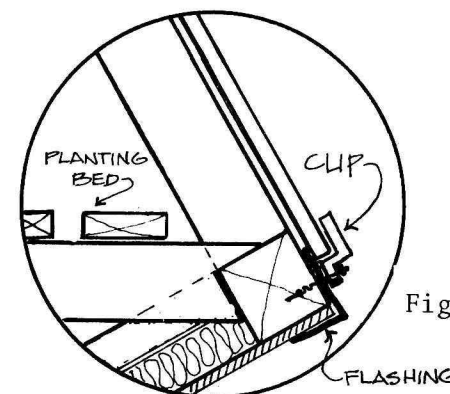
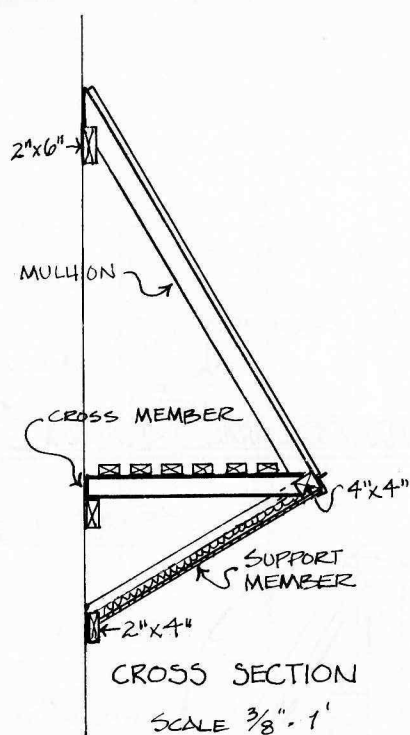


Figure 10



Step 6: Paint Mullions and Supports

Paint all surfaces, including the wooden cap strips used in the glazing detail. Use copper naphthenate or other preservative paint.

Step 7: Mount Side Panels

Side panels are nailed first to the vertical side ledgers, then the lower and upper ledgers, then to the center ledger. Care should be taken to make these corners 90° to the house. Next mount the 4x4 beam across the face of the windowbox, linking the two side panels. The 4x4 should fit exactly in the 3½"x3½" space provided in the side panels when they were constructed. (Refer to Figure 10.) Secure the 4x4 with two 16d nails at each end.

Step 8: Install Cross Piece Mullions and Supports

Next, mount the crosspieces, then place 2x4s 1" apart across the crosspieces to form the planting bed. Now, install the mullions and support members and nail into place. The triangular shape will create a stable structure.

Step 9: Install Bottom

The bottom plywood sections are cut from the remaining sheet of ½" plywood to fit over the bottom front.

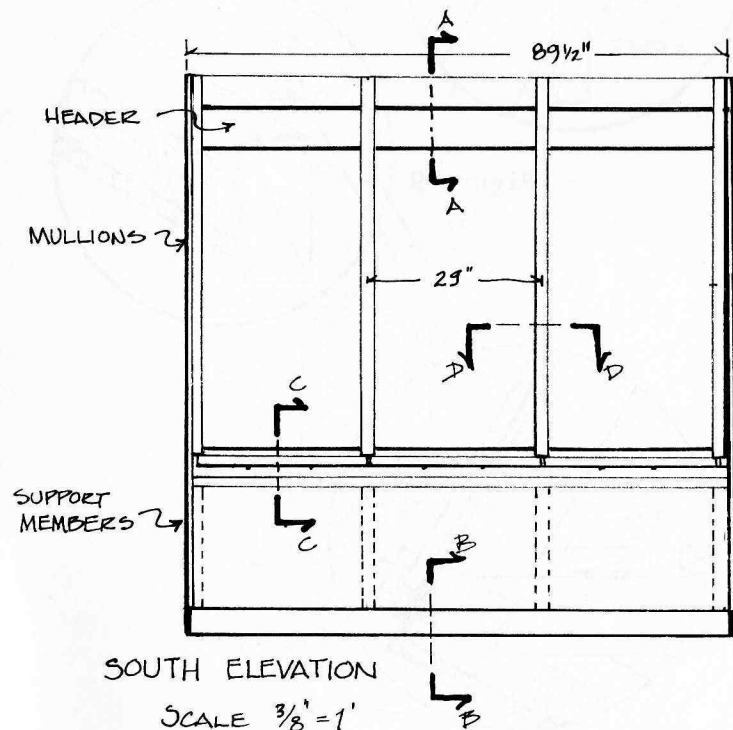
Step 10: Flashing

Cut a 117" strip of 6" flashing and crease it to give a 3"x3" 90° angle flashing. Install it with caulking along the center 4x4. Nail the flashing with 6d nails.

Drill two pilot holes at the base of each pane (between the mullions) and install two mirror clips. Be sure to replace the mirror clip screws with brass screws to prevent rusting.

Step 11: Glazing

A 3/8" square neoprene sponge strip, to help space and seal the glass, is stapled down the center faces of the mullions and along the center of the top plate. There should be ½" of mullion exposed on each side of the neoprene strip. Make sure the staples are in line with the length of the neoprene so they don't touch the glass!



Carefully take the 3/8" wide glazier's tape and lay it along the top and the two sides of each glazing section, next to the neoprene and even with the edges of the mullions. You are now ready to set in the 28"x76" strips of glass. If all the spacings are correct and square, there should be no difficulty.

Refer to the instructions on page 56 of the GREENHOUSE CONSTRUCTION chapter to complete the glazing detail for the windowbox. The only difference in procedure is seating the glass on mirror clips rather than doweling.

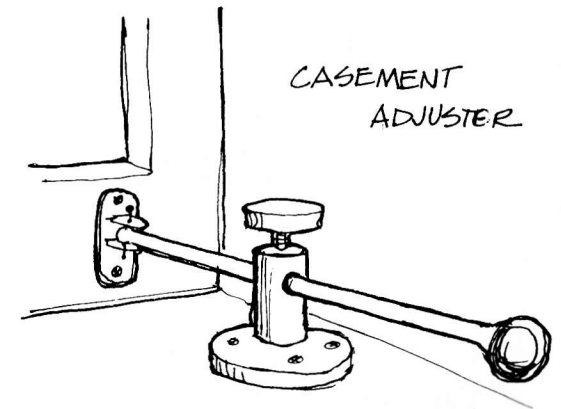
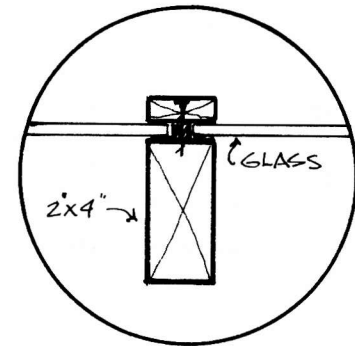
Step 12: Top Flashing

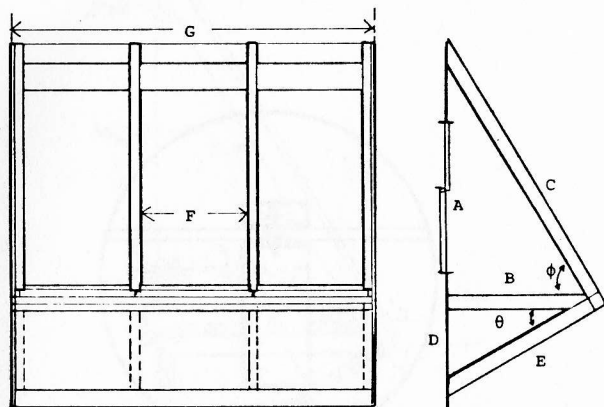
Cut the remaining 6" flashing to the full length of the windowbox and bend it in the middle to a 120° angle. Slide the flashing under the bottom of the house siding at the top of the greenhouse. Before nailing the flashing, lay a generous bead of silicone caulk across the top of the glass to insure an adequate seal.

Step 13: Exterior Finish

All plywood surfaces should be faced with siding compatible with the house. Slide the top piece of front siding under the flashing strip. Butt the siding against a 1x2 strip nailed along the edge of the windowbox sides. The door may be finished with plywood or siding as desired. Interior surfaces of the windowbox may be covered (in Step 3) or the exposed styrofoam can be painted for adequate protection. Weatherstrip the vent doors. Install casement adjusters.

You will have to experiment to determine the best operating procedures for your windowbox greenhouse. You may find it desirable to use an insulating device over the greenhouse glass at night to keep the night temperature higher, depending on the types of plants growing in the space. Any interior insulating device used must seal well at the edges.





Windowbox Materials List

- 1 8' 2x6
- 12 4½"x3/8" lag screws (hex head)
- 2 4'x8' ½" CDX plywood sheets
- 3 8' 2x2
- 4 10' 2x4
- 11 8' 2x4

- 3 28"x76" sheets of glass
- 1 8' 4x4
- 16' 24 gauge flashing, 6" wide
- 6 plastic mirror clips with replacement brass screws

- 5 8' 1x2
- 2 8' 1x3
- 3 2'x8' 1" styrofoam sheets
- 1 lb. 16d nails
- 1 lb. 8d nails
- 1 lb. 6d nails (galvanized)

- 1 jar white glue
- 2 sets 2½"x3" small door hinges
- 2 casement adjusters
- 28' 3/8"x3/8" neoprene SPONGE
- 40' 3/8" wide glazier's tape
- 1 tube silicone caulk

- 1 tube panel adhesive
- 20 #10 flathead phillips or square-drive screws
- 2 qt. copper naphthenate wood preservative paint
- 12' sponge weatherstripping

Design Procedures

There are two basic procedures for designing the dimensions to custom fit a windowbox for your house.

Method 1:

Decide how high up on the house the top of the windowbox can reach. Then determine the distance between the planting bed and the uppermost part of the windowbox. This is between 60" and 70" in the example in the GUIDE and is marked A in the figure in the left margin. The dimension B in the example is between 24" and 40", determined by the desired width of the planting bed plus 4.5" for the glazing structure. If a 24" planting bed is desired, B would be 28.5". You can then determine dimension C by the equation $C^2 = A^2 + B^2$.

Be sure that all dimensions are in the same units. Use a calculator to be exact.

Determine D by finding angle ϕ ($\tan \theta = A/B$) and subtracting it from 90° to find angle θ . Then $D = \tan \theta \cdot C$.

Dimension E is found by solving the equation:

$$E = \sqrt{B^2 + D^2}$$

Method 2:

An alternative is to draw the windowbox to scale (graph paper is useful), using known dimensions A and B as the base and finding the unknown lengths with a ruler and the unknown angles with a protractor. You must be careful to make an accurate drawing and to take careful measurements.

Food Production

A solar greenhouse can be used not only as a solar collector but also as a tool for growing food. How the greenhouse is used for growing plants depends on your food preferences, gardening habits, and the extent that you use it as a living space. You can work in your greenhouse for earlier garden starts -- there is more light than on your windowsill and a better growing environment. You can be ready early in the year with large, healthy starts that won't be susceptible to insect damage or disease.

Planting beds in your greenhouse can be constructed on waist-height benches or you may decide to plant directly into the soil. Your choice will depend on personal preference and the space and materials available. For planting boxes, use 6" to 15" of soil, depending on the rooting demands of the plants you are growing. Please refer to the section in this book on maintenance and control of the greenhouse environment to control overheating and scorching of plants in summer.

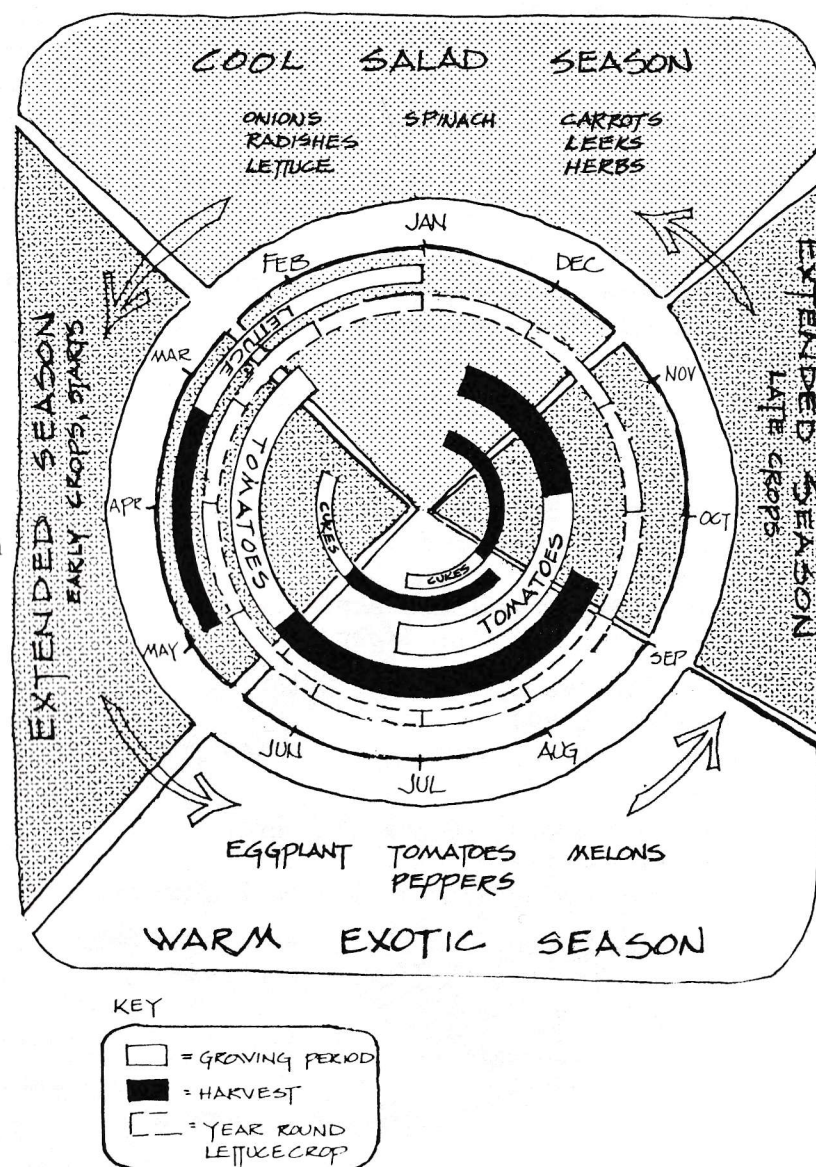
A Seasonal Rotation

The solar greenhouse extends seasonal "exotic" vegetable production in the maritime Northwest *without artificial light* from four and one-half to nine months. Year-round production of cooler weather salad crops is possible. With a careful organization of planting rhythms and consideration for seasonal light and heat changes, you can grow "exotics" and salads during times when you haven't grown vegetables before.

A basic planting timetable is included here, but it needs to be adapted to your specific greenhouse's orientation, size, temperature fluctuations and other garden characteristics such as soil condition and plant variety selection.

Seasonal use of plant species is important for healthy vegetables and for optimal food production. Take advantage of the extra heat during spring, summer and fall to grow fruiting plants for longer than their normal outside productivity. Fruiting plants include tomatoes, peppers, melons, cucumbers and eggplants. Valuable greenhouse space should not be taken up during the "heat season" with cooler weather crops that can be grown in the outside garden.

Solar Greenhouse Plant Rotation and Harvest Chart



Seed Sources

Abundant Life Seeds, Box 374

Gardiner, WA 98334

Untreated organic and sometimes locally grown.

Johnny's Selected Seeds, Albion, ME 04910

50¢

Organic, hardy. Grows a lot of his own; knowledgeable, reliable

Seattle Garden Center, Pike Place Market
Carries treated seeds, but Bob Gill knows a lot about winter gardening and is very helpful.

Tillinghast Seeds, La Conner, WA 98257

A few winter coles.

Stokes Seeds, Box 548, Buffalo, NY 14240

Wide selection commercial, much Canadian grown seed. Cheaper and better than Burpee. Many greenhouse varieties for cooler weather and low light.

William Dam, West Flamboro, Ontario,

LOR 2K0, Canada

Some good, cheap, unusual varieties for winter.

Alexander & Brown, PO Box 13, Perth

PH1 5NY, Scotland

A few good varieties for continual cropping.

Thompson & Morgan, Box 24, Somerdale, NJ 08083

US outlet for British firm. Very interesting catalog.

Tsang & Ma International, Box 294,

Belmont, CA 94002

Interesting oriental varieties. Some at Seattle Garden Center

Because of winter's low light levels in the Pacific Northwest, the exotics become less healthy, so space used for lengthened fruition can be put to more advantageous use in the late fall and winter. The lower levels of solar radiation can be better used for leaf-producing salad vegetables that thrive in a cooler environment and do not need a specific photoperiod for food production. There are varieties of salad vegetables -- mustards, cabbages, broccoli, and lettuce-- bred specifically for low light conditions. Toward the end of winter extra space is needed for seedflats to begin a cycle of planting for starts in the outside garden.

If you seed a crop 6 to 8 weeks before the time is right for your outdoor garden, when one crop is exhausted in the outdoors you have another ready to go in. For each area outside, then, you can save several weeks with each replanting.

To best use the planting area in your greenhouse, sow short term crops in between rows of long term crops or mix the seeds to get the same effect. For example, mix radish seeds with lettuce and plant them simultaneously. The radish matures first and can be eaten before it interferes with lettuce growth. The thinnings removed from heavily planted rows can also be eaten to avoid waste. Leaf lettuce plants near maturity can be made to produce more if the outer leaves are eaten and the inner heart left to continue producing new growth. Plants harvested prior to full maturity maximize overall production since plants grow slowest at maturity.

The French intensive bio-dynamic gardening system works well in tandem with the greenhouse. Work with narrow (4' wide) 20' long strips. Dig up the dirt to about 18" deep and loosen the soil as you dig. Add a lot of organic amendments -- humus, compost, manure -- so that you have healthy, loose soil. Plants growing in such healthy, soft soil will not encounter problems typical with packed soil. This soil will aerate and water better than typical garden soil.

Pest Control

Artificial fertilizers and pesticides should not be used in the enclosed environment of a greenhouse. Over-application cannot be tempered as easily as in a garden. Plant-specific application is very difficult because of the variety and close proximity of plants. A healthy soil, high in organic matter with timely organic fertilizer additions will meet the needs of growing plants and prevent insect and disease manifestations.

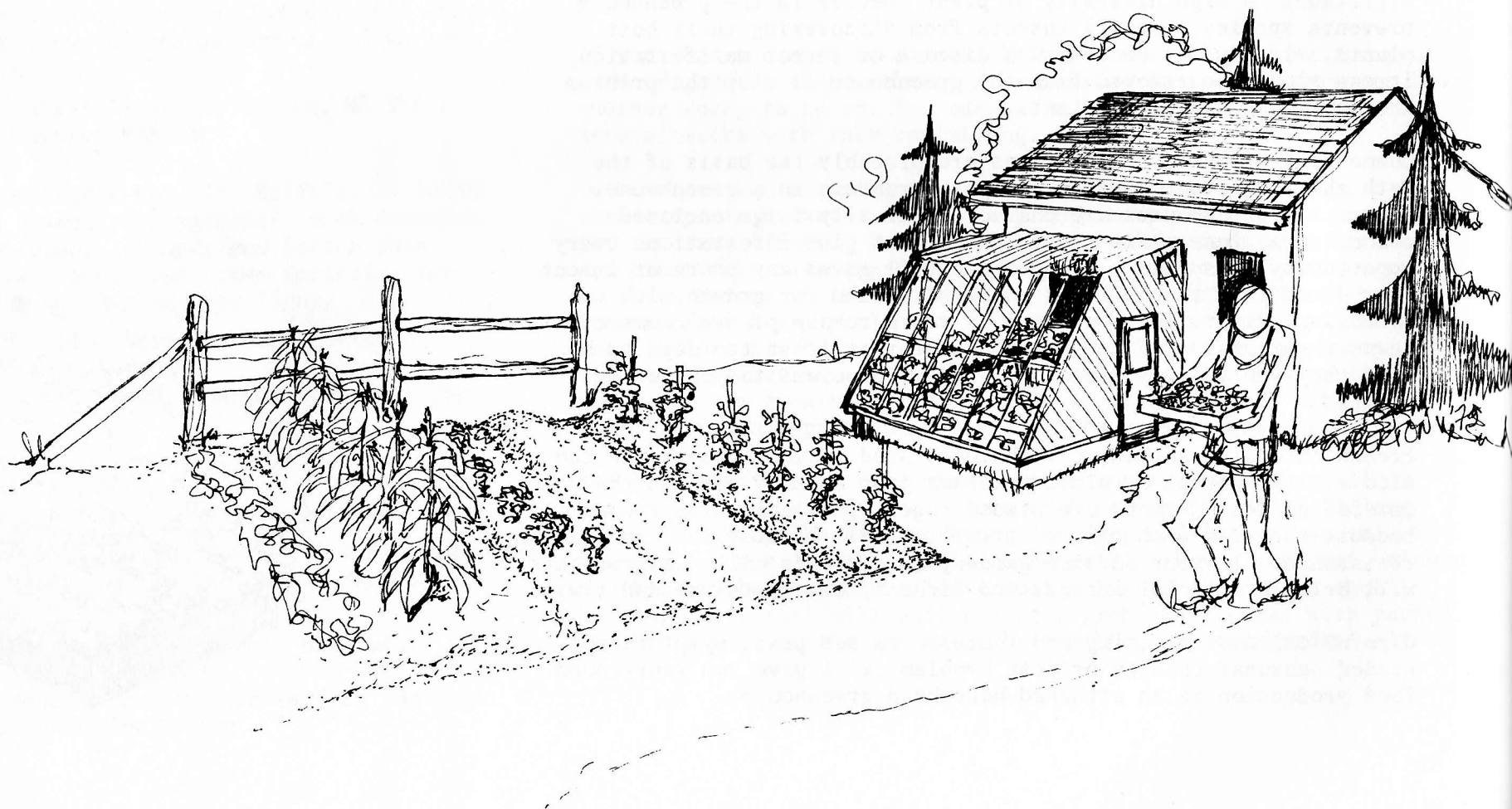
The enclosed environment will protect plants from outside insect migration. A high diversity of plant species in the greenhouse prevents species-specific insects from discovering their host plants. If a plant does show a disease or insect manifestation, it can simply be removed from the greenhouse to stop the problem from spreading to other plants.

Commercial greenhouse operations are probably the basis of the myth about constant disease and pest problems in a greenhouse. Commercial greenhouses are characteristically large enclosed monocultural (one plant type) spaces that give infestations every opportunity to spread. The sterile soil gives any spore or insect introduced into the building an ideal medium for growth with no natural predators for control. If you purchase plants commercially, leave them outside of the greenhouse for at least ten days to be sure they won't carry disease or insect problems to your other plants.

French intensive gardening techniques used in your greenhouse can also assist control of plant problems just as they work in the outside garden. Plants are placed together as companions, some because they aid each others' growth, others because they help insect resistance. In your outside garden, herb plants called attractants will bring beneficial insects and birds to eat pests you don't want.

Careful calendar planting and learning to see plant symptoms for needed seasonal changes or pest problems will give you year-round food production in an attached household greenhouse.





Greenhouse Operation

A season or two will teach you what you need to know about venting and other techniques for tempering your greenhouse. The outside temperature, the individual performance of your greenhouse, and your experiences living with the structure will determine when you should open vents, use fans, or close off the greenhouse from the living space.

Remember that when summer comes a greenhouse can get very hot. Temperatures of up to 120°F can be found in greenhouses in summer. High temperatures will burn plants and overheat your house if you do not plan for thermal controls. The section in this GUIDE on THERMAL STORAGE shows how to use thermal mass to store excess greenhouse heat, but the lag between transfer of heat from air to storage still means a very hot building.

The key to preventing overheating in summer is to limit the amount of light coming into the greenhouse. *Once the light is in, the heat is in!* You can use a fan and vents to blow out too-hot air as described in the DESIGN chapter. There are a few other tricks you can use to keep greenhouse temperatures moderated. Shading the greenhouse to keep the light out controls the summer temperature best.

Shading for the outside of the aperture (glass) can be done with some kind of awning. Cheap bamboo fencing available at garden and hardware stores is excellent for this. It prevents most light from entering, but still allows a good diffuse light to filter through to plants.

Another shading technique is to plant beans or other climbing plants in front of the greenhouse, training them as summer progresses to grow over the glass and shade the inside. A live shade must be planted *outside* to effectively keep light -- and therefore heat -- out of the greenhouse. After harvesting the beans, you'll need to wash the glass to keep the greenhouse an effective solar collector in fall and winter.

Maintenance

A well-built solar greenhouse, unlike other solar heating equipment, does not require a maintenance contract to insure quality operation and a long life. Upkeep for the greenhouse can be done in conjunction with the maintenance of your home.

Each spring or fall you should:

- Check the glazing seal along the mullions, at the bottom and top of the aperture. Caulk with silicone as needed.
- Check the roof's fiberglass overlaps and flashing for water and air leaks. Caulk and repair as necessary.
- Check the wood for weathering. Paint as needed or every five years.
- Check doors and vents for air- and weather-tight fit and smooth operation. Repair and weatherstrip as needed.
- Check the vent to the house for smooth operation and airtight closure.
- Check glass for cracks. Caulk with silicone or replace as needed.
- Clean glass at least once a year inside and out to insure good solar gain. Use non-toxic cleaners.

How to Put on a Workshop

Hands-on workshops, if properly done, are a truly fine way to share skills and information. Participants learn from each other and the teachers learn more with each workshop. The additional advantage of workshops over classroom instruction is that a working greenhouse is built amidst all the learning.

Scope of Workshop

Determining the scope of work is the first step. Several options are available. The group may build a free-standing greenhouse in a weekend or a series of weekends. A windowbox greenhouse -- or even two if the working group is large -- may be built and mounted. Or the greenhouse described in this manual may be built as an attachment to a house or commercial building. The size of the project, the planned use of the building, and the number and skills of participants will all determine how much work will be done over what period of time.

Contractual Arrangements

Workshops can be set up by the teachers or by a sponsoring organization or individual. A site-owner is usually involved in some capacity -- in many cases the owner is the sponsor. The most complex situation has a separate sponsor, teacher, site-owner and tenant.

Whenever more than one party is involved, the question of allocating responsibilities and outlining the scope of work becomes very important. Without both clear understandings and plenty of goodwill, the workshop may end up with an unfinished structure and bad feelings.

The major points that have to be made clear are:

1. **WORKSHOP LIMITS:** Everyone must understand that the primary function of a workshop is to *teach and learn* -- not to build. This fact, coupled with other factors such as participant skills, site, weather, materials availability, and tool dependability mean that the actual output of the workshop is unpredictable. Therefore, we never guarantee completion of a workshop project. We do guarantee to leave the owner-tenant in a position to complete the building, and we provide advisory support as necessary.

Pre-Workshop Organization

1. Select site (5 person days)
 2. Site survey (.5)
 3. Confirm site (.5)
 4. Building and plot plan to teachers (.5)
 5. Preliminary design (5)
 6. Design approval (.5)
 7. Building permit (1-2)
 8. Materials list to buyers (.1)
- (Registration of participants should take place during steps 4 through 8.)
9. Deliver manuals to pre-registered participants (.5) (If this is not possible, hand deliver them at the site.)
 10. Foundation (normally done by outside contractors) 10 days before workshop
 - a. excavate
 - b. build forms
 - c. building department inspection and ordering cement
 - d. pour
 - e. strip

2. AUTHORIZATION TO BUILD: You must be certain that there is clear *written* permission to proceed from the owner of the property or from the tenant if s/he has legal authority to make improvements. (The basis of this authority should be stated in the written agreement.)

3. LEGAL RESPONSIBILITY FOR ACCIDENTS: Teachers should be responsible only for injuries resulting directly from the actions of themselves or their staff. This should be stated in the written memo of agreement. This means the balance of the responsibility falls on the sponsor and the site owner or tenant. Disclaimers of responsibility by these parties, even if signed by the participant, will probably not legally prevent successful suit by participants injured because of negligence. Teachers should be covered by their employer with liability insurance.

4. PAYMENT: The amount the teachers are to be paid, time of payment, and who is to pay should be clearly specified.

5. TRAVEL, FOOD AND LODGING: If you as a teacher have to travel and pay for meals and lodging, it should be agreed that your expenses will be covered. Of course, one reason we are writing this is to spread the expertise to other teachers and minimize our own travel.

6. SCOPE OF WORK: It should be clearly stated in the memo of agreement that the teachers will do certain tasks within certain time frames for an educational purpose. For instance: give a slide show on solar greenhouses and workshop construction on Friday night, 7:30 - 9:30; conduct hands-on instructional workshops on greenhouse building from 9:00 a.m. to 5:30 p.m. on Saturday and Sunday. An overtime charge provision should be included if circumstances force work into evening hours. Although we have always been flexible about this, it is very useful to have this understanding before the workshop.

7. PUBLICITY WORK: Responsibility for PR should be clearly agreed upon to ensure that it is done and to avoid confusion. Content should also be agreed on -- teachers should be given credit in the publicity.

Pre-Workshop Organization

(During the foundation steps, also confirm the following with your teachers: room reservations, projector, chairs, the # of participants, beverages, and tools required.)

11. Inspection of foundation, site and materials by teachers (.5) Five days before workshop
12. Evening audio visual presentation (.4)
13. Construction of greenhouse
14. Finish construction (2)
15. Post-construction inspection (1)
16. Follow-up interview with owners (.5)
17. Debrief sponsors (.5)
18. Follow-up one year later

Friday Afternoon

Establish geometry of the greenhouse with sills and ledgers.
 Attach 2x6 ridge member and post.
 Place fiberglass insulation under and behind all sills and ledgers for proper seal; caulk if necessary.
 Adjust for square and level.
 Inventory materials; obtain any missing or additional materials.

8. ENROLLING PARTICIPANTS AND TAKING FEES: There must be clear agreement about who registers participants, takes fees, and answers questions. Registration materials and PR should direct potential participants to the proper person. This is an important job and involves a lot of work. It is necessary to have registration in only one place and that registration people are kept well-informed of the planned program and other details. Inconsistency creates confusion.

9. MATERIALS PURCHASE: It must be clear who orders and picks up building materials and who pays for them. In most cases, the owner or tenant pays for materials, but the sponsor acts as purchasing agent, with the teachers (if separate from the sponsor) giving advice about fair prices, substitutions, and sources of supply.

10. CODE AND PERMITS: In all cases there is the possibility that a building inspector will become involved in the process -- the likelihood depends on your location. It is wise to agree in advance about who is responsible for dealing with this. In many areas, that party will be automatically applying for permits. In most areas, the owner or tenant should be responsible because technically s/he is doing the building -- and the Codes generally allow an owner to do the work rather than forcing use of a licensed carpenter. The owner-tenant will need support from the teachers in applying for a permit. The extent of this aid will vary with each workshop from advice to complete plans.

11. PLANS AND DRAWINGS: There should be a complete understanding about the types of planning and the technical level of drawings the teachers will supply. These can range from sketches and ideas to complete materials lists, working drawings and plot plans needed to get building permits. The amount of fee charged by the teachers can be greatly affected by the plan requirements.

12. WORKSHOP MANAGEMENT: There should be a cordial but clear understanding about who runs the workshop as far as the participants are concerned. Because this is primarily an educational experience, it should be agreed that the teachers manage the workshop.

The tenant-owner has important interests and should be approached by the teachers to make sure they are considered. The sponsor should not be an overt presence, but should be free to advise the teaching staff discreetly, if necessary.

13. MAINTENANCE AND REPAIR AFTER THE WORKSHOP: The greenhouse described in this manual is a good quality solar system, but no building stands forever without requiring maintenance or repair. Information should be provided to the greenhouse's owner about regular maintenance and repair. The written agreement should clearly delineate the teacher's and the sponsor's responsibilities if the owner has problems with the greenhouse.

14. LUNCH AND CHILDCARE: Be sure to have scheduled breaks and, if possible, hot or cold drinks to cheer the workers. Will refreshments and lunch be supplied or will participants be asked to bring their own? It is important that these points be made in the registration materials. The same is true for childcare-- if it is to be provided, arrangements must be made and a notice given far in advance. If at all possible, try to provide childcare since this means more women will have an opportunity for learning skills that might otherwise be closed to them.

Without goodwill, a written document containing all of the above will not work. But a comprehensive, clear agreement on each of these points will help maintain goodwill. Writing is not necessary but it sometimes helps people remember what they agreed to. Apply these considerations to your own situation and the form, written or oral, will be obvious.

Workshop Preparation

FINDING A SITE: The first task is to find a site and reach the necessary agreements with the owner-tenant. Remember this is a do-it-yourself technology. The owner should be enthusiastic and willing to try. Never do a workshop where the owner-tenant cannot or will not be a participant. The site must be surveyed for suitable solar access and workshop space.

Friday Evening

GENERAL INTRODUCTION:

Sponsor, teachers, owner-tenant.
Film: *Build Your Own Greenhouse-Solar Style*
How solar greenhouses work.
Solar greenhouses for energy conservation.

SLIDE LECTURE:

National overview of solar and greenhouses.
Methods of operation.
Construction.
Regional and local food production.
Greenhouse as heating system.

DISCUSSION:

Economics of food and heat production.
Regional payback on investment.
Performing a solar survey.
Overview of workshop activities.
Tool use and construction techniques.
Team organization.
Question answering.

Saturday Morning

WEST WALL TEAM:

Lay out west face of greenhouse.
 Cut eight 2x4s to 7'½" each, notch at the bottom to accept 1x2.
 Mark spacings on sill and top plate (24 3/4" for mullions, 24" on center for studs).
 Assemble studs with sill and plant on the ground and nail together.
 Cut 23¼" purlins and nail in at mid point.
 Square up frame, tack on temporary diagonal brace to maintain square.
 Raise frame, check for level and square, support temporarily.
 Measure first two rafters and nail into joist hangers.
 Bolt at foundation with lag screws.
 Finish installing rafters.
 Install purlins in rafters.
 Finish door and vent detail.
 Paint.

EAST WALL TEAM:

Design door, vent and window detail.
 Frame, using same procedure as west wall.
 Erect and tie in with rafters.
 Finish purlins in rafters.
 Finish door and vent detail in wall.
 Construct door and vent.
 Paint.

SOUTH FACE TEAM:

Frame in with mullions according to glazing detail dimensions; notch at bottom for 1x2
 Install purlins and header.

Paint all surfaces, including caps, wiggleboard, half-round and moulding.

SETTING A DATE: Pick a date far enough in advance to be able to prepare adequately. If this is your first workshop, make it two months, minimum. For anyone it takes at least a month. The further in advance you can prepare and publish a workshop schedule, the more potential participants can plan to attend. Schedule it for a weekend -- workshops done in midweek usually can't be attended by working people -- unless you are working with an existing group of people in a classroom or similar training situation. Make sure there are no conflicts with other events your potential participants might be interested in.

DO PUBLICITY AND SET UP REGISTRATION: It is important to set up registration before PR goes out. The workshop dates, times and event locations must be stated. Registration materials should also inform participants about what to expect, what to bring and what to wear. Unclear expectations can lead to dissatisfaction with the workshop. The registration form should also collect some information about what the backgrounds and skills of participants are and what they hope to learn.

At the time a registration is paid, it is really helpful if that participant receives a GUIDE. Keep track of who has GUIDES and include a remainder to bring them to the workshop.

The best publicity continues to be word of mouth. The next best thing is an advance schedule or notice in a newsletter with a relevant audience. The most effective publicity medium in our area is radio. Public service announcements in community-oriented radio and newspapers are at least as effective as any kind of paid advertising. Radio and television need advance notice of at least two weeks; printed media needs at least a week, longer for monthly publications. Invite them to cover the workshop as well as publicize it.

Most registrations will be received in the last week before the workshop, no matter what you do. So once you set up the workshop, proceed to do it as planned.

To close out registration make sure that someone keeps track of it throughout the workshop -- lists of names, addresses, and fees. Ideally this should be the same person or persons who do advance registration records.

PLAN THE SYSTEM: Obviously, the greenhouse must be planned in advance in order to buy materials, avoid surprises, and maximize the construction and learning efficiency of the workshop. A foundation plan, a design for the greenhouse itself and its attachment to the existing building, and any additional information required by the building department if a permit is needed are part of the planning. A site visit will be necessary to assess the existing structure and the doors and windows to link the greenhouse to the house, landscaping or possible obstacles, and solar potential of the site. Recyclable materials available on-site should also be assessed.

At the simplest, a sketch of the existing building and method of attachment in addition to the design presented in this manual will be necessary to guide the workshop planning, materials purchase, and organization of crews involved during the workshop. For Code permits, more extensive work may be needed such as detailed drawings and complete materials lists.

Even the best plans will be changed during actual construction. The best approach is to plan carefully, pay attention to details, and be flexible when faced with certain doom.

PLAN THE WORKSHOP: After the greenhouse is planned, the *practical* goal of the workshop is clear. Everyone involved should know ahead of time how the work will be divided. The best method is to visualize the tasks and their time relationships in a flow chart or simple list. A plan can then be worked out for who will coordinate each task. We have a tradition of using "interns" who help us in return for workshop participation at no cost. This may be someone who is willing to do support work such as picking up materials or who has a specific skill they are willing to teach. This frees experienced people for more general coordination of workshop activities.

Saturday Afternoon

Break into teams for glazing, sheathing and "tightening up"

GLAZING TEAM:

Lay out flashing at bottom, install dowel pegs.
Staple neoprene and lay down glazier's tape.
Put in glass and screw down cap pieces.

EXTERIOR SHEATHING TEAM:

Staple up tar paper.
Nail and trim cedar siding.
Caulk where necessary.

INTERIOR SHEATHING TEAM:

Staple up fiberglass insulation.
Nail in 1" Dow SM insulation.
Nail plywood on inside wall; finish.

ROOF TEAM:

Caulk and nail wiggleboard and half-round pieces.
Insert flashing under main house siding.
Silicone wiggleboard and half-rounds; lay corrugated fiberglass.
Lay flashing down and caulk.

DOOR AND VENT TEAM:

Hang door and vent.
Weatherstrip and attach hardware.
Caulk and paint.

Sunday Morning

Finish Details of Greenhouse.
Review Construction Process.

Sunday Afternoon

Planting box construction.
Place barrels in greenhouse and fill
with water.
Put planting boxes in place and fill.
Discuss operation of greenhouse for
optimum food production and
heat collection.
Critique and debriefing.

WORKSITE PLANNING: A specific part of planning is to decide where the different crews will work. Review the construction procedure carefully to note details (such as location of electric outlets if power tools will be used) and plan what will be done where. If crews can see each other, the information sharing is more automatic, but there must be enough room to work safely and effectively. Thirty people building parts of a 10'x16' greenhouse take up a lot of space. If weather turns bad, it is absolutely necessary to have an emergency plan for getting some of the building work under cover. Many times a neighbor's carport has come in handy!

BUY MATERIALS: At least a week before the workshop (four weeks, if you've never done it before), start buying the materials. The best way is to call around, find good prices, place an order, and pick everything up in one or two trips. Keep all receipts.

Careful planning will make it possible to minimize travel and buy in larger quantities (which makes merchants happy and may get you discounts). Buy wholesale whenever possible.

Plan for emergencies -- make sure you know of a hardware store open on the days of the workshop in case you forget something or an unexpected tool or material is needed. Inventory the materials before the workshop begins to insure that everything was purchased according to specification.

GETTING THE TOOLS: Lack of the right tools at the right time, like lack of materials, can slow down or stop a whole workshop. You need to have enough tools for all crews who will need the same thing at once. Tools needed break down into two categories:

1. **COMMON TOOLS:** Hammers, short tape measures, tri-squares, screwdrivers, drills, etc. Many participants will have these tools. People may be asked by the registration information to bring tools for their own use, and they may be reminded just before the workshop, if possible. Warn participants to mark their tools well and have marking equipment available at the workshop.

2. UNCOMMON OR SPECIAL TOOLS or tools so important that their availability can't be left to chance: ladders, extension cords, Robertson screwdrivers, saber saws and circular saws (if needed), chalk lines, caulk guns, chisels, planes, paint brushes and paint, and at least four sets of sawhorses. Prepare to have it all taken care of in advance, whether you bring, borrow or rent the tools.

Take an inventory of the tools before the workshop begins and immediately after finishing work. One person should have this delegated responsibility.

A NOTE ABOUT TOOLS: We have led workshops both with and without power tools. The peace and safety of the workshop without power tools seems greater. Another benefit is that participants who are not familiar with power tools are less threatened in a learning situation where other participants have greater skill. Using hand tools is no handicap when there are many participants and time is not pressing the workers. If you do decide to use power tools, take care to see that everyone is acquainted with their safe operation.

Be careful! It is very easy in the construction situation for participants who are well-acquainted with building to monopolize the tools and complicated tasks and for lesser-trained or/and timid participants to lose out in the building experience. Remember that the workshop is to learn, not to finish the building and work as a teacher or participant to be sure that everyone has a chance to use new tools, learn new techniques, and to fully participate in the building process.

Doing the Workshop

REGISTRATION AND CHECK-IN: Make sure that someone is responsible for checking in registered participants, registering people (if it's still open) and keeping track of the checks and money. This person should be on the job before the initial lecture program and at least as far into the workshop as noon the first morning.

Tools

FOR LEADING A WORKSHOP:

- 2 shovels: 1 spade, 1 square
- 3 hammers: framing and 16 ounce
- 1 circular saw, with extra blades
- 2 electric drills with bits
- 2 levels
- 3 tape measures (2-16', 1-50')
- 2 combination squares
- 1 carpenter's steel square
- 1 staple gun with staples
- 1 wheelbarrow (for foundation)
- 1 rasp or surform-type plane
- 1 plane, block or jack
- 1 tin snips
- 2 caulk guns
- 2 pliers
- 2 50' extension cords
- 1 chalk line
- 1 mechanic's tool set with sockets
- 1 sledge hammer
- 1 set of nail sets
- 4 10" parallel clamps
- 4 8" 'C' clamps
- 1 set of chisels
- 2 pairs of saw horses
- 2 carpenter's tool aprons
- 4 R-2 drivers for Robertson screws
- 3 ladders: 1 step, 1-8', 1-16' rung
- 1 miter box with backsaw
- 1 glass cutter with oil
- 2 pair safety glasses or goggles
- 2 pair sound-deadening earphones
- 2 respirators with extra filters
- 2 pair of gloves
- 1 bevel marking gauge
- 1 jigsaw or keyhole saw
- carpenter's pencils
- clean-up equipment
- string
- painting equipment: brushes, rollers, trays, thinner

Tools

PARTICIPANT TOOLS:

Simple necessities:

pencil, notebook and camera
 weatherproof clothing
 safety equipment: goggles, earphones,
 gloves, etc.
 tape measure
 combination square
 hammer
 saw

More comprehensive:

carpenter's square
 extension cord
 drill and bits
 skill saw
 level
 chalk line
 screwdrivers
 staple gun and staples
 ladders (step and 8')
 caulk gun
 carpenter's apron
 chisels
 plane (block or jack)
 painting equipment

INTRODUCTION, LECTURE/SLIDE SHOW: We always kick-off our hands-on workshops with a lecture/slide show, usually done the evening before the actual construction begins. First, the teachers and site-owner or tenant are introduced by the sponsor. We then have a slide show introducing the reasons for building a solar greenhouse, giving a broad picture of the history and technology of solar heating, explaining how the greenhouse to be built works, and showing step-by-step photos of the work we'll soon begin. All sections of this presentation have examples of different greenhouses in operation. (We will soon have a comprehensive slide show to rent. Contact ECOTOPE if you are interested.)

After the slide show, the plan for the workshop should be presented and participants should sign up for crews. People feel more comfortable about this if they know there will be good information exchanges between crews. Reminders about food, clothing and tools should be given. If the workshop site is different from the lecture site and is hard to find, maps should be made available.

CONSTRUCTION DAYS: Teachers should arrive early enough to set up work stations with materials, tools and electricity where needed. Proceed with the work as outlined. Keep the pace relaxed and the spirit jovial. Be sure to have enough teachers on hand so that everyone is kept busy and has assistance solving problems as they arise.

REVIEW: It is important to have a critique and review toward the end of the workshop rather than to let everyone drift off. This should happen briefly at the end of the first day and in the early afternoon of the last day. This can be a sharing of experiences, ideas and viewpoints, as well as congratulations all around for work well done. This is also a good opportunity for feedback on how well the teachers did (and how we at ECOTOPE did, if you used our GUIDE). An evaluation form can be sent later to those who participated to get thoughtful, written comments. A debriefing with the tenant-owner and sponsor should be scheduled soon after the workshop is completed.

Food Production

A solar greenhouse can be used not only as a solar collector but also as a tool for growing food. How the greenhouse is used for growing plants depends on your food preferences, gardening habits, and the extent that you use it as a living space. You can work in your greenhouse for earlier garden starts -- there is more light than on your windowsill and a better growing environment. You can be ready early in the year with large, healthy starts that won't be susceptible to insect damage or disease.

Planting beds in your greenhouse can be constructed on waist-height benches or you may decide to plant directly into the soil. Your choice will depend on personal preference and the space and materials available. For planting boxes, use 6" to 15" of soil, depending on the rooting demands of the plants you are growing. Please refer to the section in this book on maintenance and control of the greenhouse environment to control overheating and scorching of plants in summer.

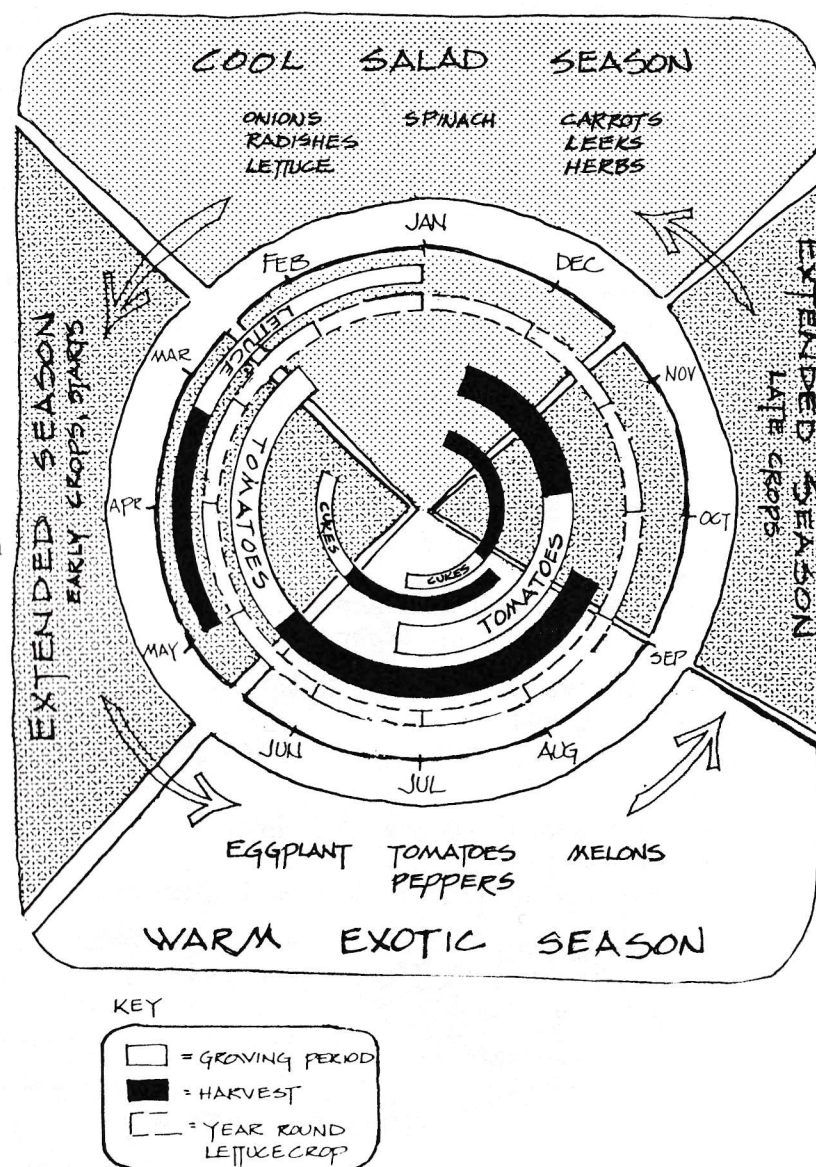
A Seasonal Rotation

The solar greenhouse extends seasonal "exotic" vegetable production in the maritime Northwest *without artificial light* from four and one-half to nine months. Year-round production of cooler weather salad crops is possible. With a careful organization of planting rhythms and consideration for seasonal light and heat changes, you can grow "exotics" and salads during times when you haven't grown vegetables before.

A basic planting timetable is included here, but it needs to be adapted to your specific greenhouse's orientation, size, temperature fluctuations and other garden characteristics such as soil condition and plant variety selection.

Seasonal use of plant species is important for healthy vegetables and for optimal food production. Take advantage of the extra heat during spring, summer and fall to grow fruiting plants for longer than their normal outside productivity. Fruiting plants include tomatoes, peppers, melons, cucumbers and eggplants. Valuable greenhouse space should not be taken up during the "heat season" with cooler weather crops that can be grown in the outside garden.

Solar Greenhouse Plant Rotation and Harvest Chart



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Heat Loss Charts of the Solar Remodel Example for Other Northwest Locations

ASTORIA

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	753	16.8	1.5	.4	14.9	8.1	6.2	1.77	4.43
Feb	622	13.9	1.5	.6	11.8	6.7	4.6	2.68	1.92
Mar	636	14.2	1.5	.8	11.9	6.8	4.5	3.96	.54
Apr	480	10.7	1.5	.7	8.5	5.2	3.0	4.19	-
May	363	8.1	1.5	.7	5.9	3.9	1.7	4.76	-
Jun	231	5.2	1.5	.6	3.1	2.5	.4	4.32	-
July	146	3.3	1.5	.7	1.1	1.6	-	-	-
Aug	130	2.9	1.5	.7	2.2	1.4	-	-	-
Sep	210	4.7	1.5	.8	3.9	2.3	-	-	-
Oct	375	8.4	1.5	.8	6.1	4.0	1.7	3.65	-
Nov	561	17.5	1.5	.5	12.0	6.0	4.0	4.0	1.69
Dec	679	15.1	1.5	.4	13.2	7.3	5.4	5.4	3.89
Total					94.6		31.5		12.5

PROSSER

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	1074	23.9	1.5	.7	21.7	11.6	9.4	3.02	6.38
Feb	806	18	1.5	.9	15.6	8.7	6.3	4.3	2
Mar	651	14.5	1.5	1.0	12.0	7.0	4.5	5.46	-
Apr	388	8.6	1.5	.9	6.2	4.2	1.8	6.08	-
May	198	4.4	1.5	.8	2.1	2.1	-	-	-
Jun	57	1.2	1.5	.7	-	.6	-	-	-
July	0	-	1.5	.8	-	-	-	-	-
Aug	6	.1	1.5	1.0	-	.06	-	-	-
Sep	115	2.5	1.5	1.2	-	1.2	-	-	-
Oct	380	8.4	1.5	1.1	5.8	4.1	1.5	5.36	-
Nov	754	16.8	1.5	.8	14.5	8.1	5.8	3.31	2.49
Dec	941	21	1.5	.6	18.9	10.1	8.0	2.7	5.3
Total					96.8		37.3		16.2

CORVALLIS

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	822	18.3	1.5	.5	16.3	8.9	6.9	2.04	4.86
Feb	647	14.4	1.5	.4	12.5	7.0	5.1	2.12	2.98
Mar	611	13.6	1.5	.6	11.5	6.6	4.5	3.2	1.3
Apr	417	9.3	1.5	.6	7.2	4.5	2.4	3.51	-
May	273	6.1	1.5	.6	4.0	2.9	.8	4.53	-
Jun	144	3.2	1.5	.6	3.1	1.5	-	-	-
July	37	.8	1.5	.7	-	.4	-	-	-
Aug	31	.7	1.5	.7	-	.3	-	-	-
Sep	111	2.5	1.5	.8	.2	1.2	-	-	-
Oct	338	8.6	1.5	.7	6.4	3.6	1.4	3.54	-
Nov	594	13.2	1.5	.4	11.3	6.4	4.5	1.89	2.61
Dec	729	16.3	1.5	.3	14.5	7.9	6.1	1.24	4.86
Total					85.0		31.7		16.6

SPOKANE

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	1231	27.4	1.5	.7	25.2	13.3	11.1	2.89	8.21
Feb	980	21.9	1.5	.8	19.6	10.6	8.3	3.71	4.59
Mar	834	18.6	1.5	.8	16.3	9.0	6.7	5.07	1.63
Apr	531	11.8	1.5	.8	9.5	5.7	3.4	5.17	-
May	288	6.4	1.5	.8	4.1	3.1	.8	5.6	-
Jun	135	3	1.5	.7	.8	1.4	-	-	-
July	9	.2	1.5	.8	-	.1	-	-	-
Aug	25	.5	1.5	.9	-	.2	-	-	-
Sep	168	3.7	1.5	1.0	1.2	1.8	-	-	-
Oct	493	11	1.5	.9	8.6	5.3	2.9	4.42	-
Nov	879	19.6	1.5	.7	17.4	9.5	7.3	2.81	4.49
Dec	1082	24.1	1.5	.5	22.1	11.7	9.7	1.94	7.76
Total					124.5		50.2		26.7

Figures shown are in MBTU

Insolation Data for the Pacific Northwest

The following insolation data is reprinted with permission from:

Insolation on South Facing Tilted Surfaces: Pacific Northwest Locations
by M. Steven Baker and John S. Reynolds, Center for Environmental
Research, School of Architecture and Allied Arts, University of
Oregon, Eugene, copyrighted 1975.

Vancouver, B.C. 49°16'

12-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	103	198	279	341	380	393	379
	Diffuse	151	132	113	98	86	78	76
KT = 0.30	Reflected	0	7	13	18	22	25	25
	TOTAL	254	336	405	457	488	496	480
February	Direct	262	413	535	620	664	662	615
	Diffuse	243	211	182	157	138	125	121
KT = 0.38	Reflected	0	13	25	36	44	49	51
	TOTAL	505	637	742	813	845	836	787
March	Direct	506	662	773	831	833	778	670
	Diffuse	379	330	284	245	215	196	190
KT = 0.43	Reflected	0	23	44	63	77	85	88
	TOTAL	885	1015	1101	1139	1124	1059	948
April	Direct	810	916	963	947	868	732	548
	Diffuse	536	466	402	346	304	277	268
KT = 0.47	Reflected	0	35	67	95	117	130	135
	TOTAL	1346	1417	1432	1388	1288	1138	951
May	Direct	1234	1276	1249	1148	977	750	484
	Diffuse	635	553	476	411	360	328	318
KT = 0.54	Reflected	0	48	93	132	162	181	187
	TOTAL	1869	1878	1819	1690	1499	1259	989
June	Direct	1188	1182	1120	996	817	595	350
	Diffuse	703	612	527	455	399	364	352
KT = 0.50	Reflected	0	49	95	134	164	183	189
	TOTAL	1891	1844	1742	1584	1379	1141	891
July	Direct	1351	1368	1315	1188	991	740	456
	Diffuse	651	567	489	421	369	337	326
KT = 0.55	Reflected	0	52	100	142	173	193	200
	TOTAL	2002	1987	1904	1750	1534	1270	982

Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1142	1244	1271	1216	1084	882	627
	Diffuse	558	486	418	361	316	288	279
KT = 0.55	Reflected	0	44	85	120	147	164	170
	TOTAL	1700	1774	1774	1697	1547	1335	1076
September	Direct	706	874	982	1023	995	899	742
	Diffuse	433	377	325	280	246	224	217
KT = 0.49	Reflected	0	29	57	81	99	110	114
	TOTAL	1139	1280	1364	1384	1339	1233	1072
October	Direct	360	530	665	754	792	776	707
	Diffuse	282	245	211	182	160	146	141
KT = 0.42	Reflected	0	17	32	45	56	62	64
	TOTAL	642	792	908	982	1007	984	912
November	Direct	136	248	343	415	458	471	451
	Diffuse	170	148	127	110	96	88	85
KT = 0.33	Reflected	0	8	15	22	27	30	31
	TOTAL	306	404	486	546	581	588	566
December	Direct	66	137	199	247	278	291	283
	Diffuse	125	109	94	81	71	65	63
KT = 0.27	Reflected	0	5	10	14	17	19	19
	TOTAL	192	252	303	342	366	374	365

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
VANCOUVER, B.C.

DEC-JAN	223	294	354	399	427	435	423
NOV-MARCH	428	527	606	657	678	668	626
OCT-APRIL	589	692	767	808	813	781	714
ALL YEAR	1064	1138	1167	1150	1084	977	835

Seattle-Tacoma, WA 47°27'

19-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	112	204	282	341	377	387	370
	Diffuse	169	147	127	109	96	87	84
KT = 0.30	Reflected	0	7	14	20	24	27	28
	TOTAL	280	358	422	470	497	501	483

February	Direct	288	440	562	646	685	678	625
	Diffuse	261	227	196	169	148	135	130
KT = 0.38	Reflected	0	14	27	39	48	53	55
	TOTAL	549	682	785	853	881	866	810

March	Direct	579	746	861	918	912	844	719
	Diffuse	398	346	298	257	226	206	199
KT = 0.46	Reflected	0	25	49	69	85	94	98
	TOTAL	977	1117	1208	1244	1222	1144	1015

April	Direct	875	980	1021	996	905	754	555
	Diffuse	548	477	411	355	311	284	274
KT = 0.49	Reflected	0	37	71	101	123	137	142
	TOTAL	1423	1494	1504	1451	1339	1175	971

May	Direct	1220	1254	1218	1110	935	706	442
	Diffuse	642	559	482	415	364	332	321
KT = 0.53	Reflected	0	48	93	132	161	180	186
	TOTAL	1862	1861	1793	1657	1460	1218	950

June	Direct	1241	1229	1156	1019	826	590	334
	Diffuse	698	608	523	451	396	361	349
KT = 0.52	Reflected	0	50	97	137	168	187	194
	TOTAL	1939	1887	1777	1608	1390	1139	877

July	Direct	1448	1458	1392	1247	1029	755	449
	Diffuse	643	560	482	415	364	332	321
KT = 0.58	Reflected	0	54	105	148	181	202	209
	TOTAL	2091	2072	1979	1810	1574	1289	979

Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1135	1227	1243	1180	1041	837	582
	Diffuse	569	495	426	368	322	294	284
KT = 0.55	Reflected	0	44	85	120	148	165	170
	TOTAL	1703	1766	1755	1668	1511	1295	1036

September	Direct	785	958	1066	1102	1062	950	774
	Diffuse	443	386	332	286	251	229	221
KT = 0.52	Reflected	0	32	61	87	106	119	123
	TOTAL	1228	1375	1460	1475	1420	1298	1118

October	Direct	414	596	737	828	862	838	757
	Diffuse	301	262	226	195	171	156	151
KT = 0.44	Reflected	0	19	36	51	62	69	72
	TOTAL	715	877	999	1073	1095	1063	979

November	Direct	183	320	435	520	569	580	552
	Diffuse	189	164	142	122	107	98	94
KT = 0.36	Reflected	0	10	19	26	32	36	37
	TOTAL	372	494	595	668	709	714	683

December	Direct	88	173	246	302	337	350	338
	Diffuse	144	125	108	93	82	74	72
KT = 0.29	Reflected	0	6	12	16	20	22	23
	TOTAL	232	304	365	411	439	446	433

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
SEATTLE-TACOMA, WASHINGTON

DEC-JAN	256	331	394	440	468	474	458
NOV-MARCH	482	590	674	727	747	732	683
OCT-APRIL	649	760	839	880	882	843	767
ALL YEAR	1118	1193	1222	1201	1129	1013	861

Spokane, WA 47°37'

19-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	240	440	610	738	817	839	804
	Diffuse	173	151	130	112	98	89	87
	KT = 0.44 Reflected	0	11	21	29	36	40	41
	TOTAL	413	601	760	880	950	968	932
February	Direct	465	712	910	1047	1112	1101	1015
	Diffuse	265	230	198	171	150	137	132
	KT = 0.51 Reflected	0	19	37	52	63	71	73
	TOTAL	730	961	1145	1269	1325	1308	1220
March	Direct	786	1014	1172	1250	1243	1152	982
	Diffuse	386	336	290	250	219	200	193
	KT = 0.55 Reflected	0	30	59	83	102	113	117
	TOTAL	1172	1380	1520	1583	1564	1465	1292
April	Direct	1125	1261	1315	1283	1167	973	717
	Diffuse	523	456	393	338	297	271	262
	KT = 0.56 Reflected	0	43	82	117	143	159	165
	TOTAL	1648	1759	1790	1738	1606	1403	1144
May	Direct	1451	1493	1451	1323	1116	844	530
	Diffuse	613	534	460	396	348	317	307
	KT = 0.59 Reflected	0	53	103	146	179	199	206
	TOTAL	2065	2080	2014	1866	1642	1360	1043
June	Direct	1565	1550	1459	1288	1045	748	424
	Diffuse	658	573	494	425	373	340	329
	KT = 0.59 Reflected	0	58	111	157	193	215	222
	TOTAL	2223	2181	2064	1870	1610	1303	976
July	Direct	1863	1877	1794	1607	1328	976	582
	Diffuse	567	493	425	366	321	293	283
	KT = 0.67 Reflected	0	63	121	172	210	235	243
	TOTAL	2430	2434	2340	2145	1860	1504	1109

Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1509	1632	1655	1573	1389	1117	778
	Diffuse	508	442	381	328	288	263	254
	KT = 0.65 Reflected	0	52	101	143	175	195	202
	TOTAL	2017	2127	2137	2044	1852	1575	1234
September	Direct	1078	1318	1468	1518	1465	1312	1069
	Diffuse	400	348	300	259	227	207	200
	KT = 0.62 Reflected	0	38	74	105	128	143	148
	TOTAL	1478	1705	1842	1881	1820	1661	1417
October	Direct	557	804	995	1119	1166	1134	1025
	Diffuse	298	259	224	193	169	154	149
	KT = 0.53 Reflected	0	22	43	60	74	83	86
	TOTAL	855	1085	1262	1372	1410	1371	1260
November	Direct	259	453	617	738	809	825	785
	Diffuse	191	166	143	123	108	99	95
	KT = 0.44 Reflected	0	12	22	32	39	43	45
	TOTAL	450	631	782	893	957	968	926
December	Direct	139	273	389	478	535	555	537
	Diffuse	145	126	109	94	82	75	72
	KT = 0.36 Reflected	0	7	14	20	25	27	28
	TOTAL	284	407	512	592	642	657	638
AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)								
SPOKANE, WASHINGTON								
DEC-JAN		348	504	636	736	796	813	785
NOV-MARCH		609	794	941	1040	1084	1069	998
OCT-APRIL		792	973	1108	1187	1205	1161	1057
ALL YEAR		1317	1449	1516	1512	1437	1295	1098

Astoria, OR 46°9'

18-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	138	245	335	402	441	451	430
	Diffuse	182	159	137	118	103	94	91
KT = 0.32	Reflected	0	8	16	23	28	31	32
	TOTAL	321	412	488	542	572	576	553
February	Direct	326	488	617	704	743	731	669
	Diffuse	275	239	206	178	156	142	137
KT = 0.40	Reflected	0	16	30	42	52	58	60
	TOTAL	601	743	853	924	951	931	867
March	Direct	601	765	877	929	917	844	712
	Diffuse	409	356	307	265	232	212	205
KT = 0.46	Reflected	0	26	51	71	87	98	101
	TOTAL	1010	1147	1234	1265	1237	1153	1018
April	Direct	858	955	989	959	865	715	518
	Diffuse	554	482	416	358	314	287	277
KT = 0.48	Reflected	0	37	71	100	122	136	141
	TOTAL	1412	1474	1476	1417	1302	1138	937
May	Direct	1153	1179	1140	1032	863	644	394
	Diffuse	654	569	490	423	371	338	327
KT = 0.51	Reflected	0	47	90	128	156	175	181
	TOTAL	1807	1795	1721	1583	1390	1156	902
June	Direct	1121	1106	1035	906	728	513	281
	Diffuse	704	613	528	455	399	364	352
KT = 0.49	Reflected	0	47	91	129	158	176	183
	TOTAL	1825	1766	1654	1491	1285	1053	816
July	Direct	1252	1256	1193	1062	869	629	364
	Diffuse	669	582	502	432	379	346	334
KT = 0.53	Reflected	0	50	96	136	166	186	192
	TOTAL	1921	1888	1791	1630	1414	1161	891

Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1106	1189	1198	1131	991	788	539
	Diffuse	579	504	434	374	328	299	289
KT = 0.53	Reflected	0	44	84	119	146	163	168
	TOTAL	1685	1737	1717	1624	1465	1250	997
September	Direct	868	1050	1160	1192	1142	1014	818
	Diffuse	445	387	333	287	252	230	222
KT = 0.54	Reflected	0	34	66	93	114	127	131
	TOTAL	1313	1471	1559	1572	1508	1371	1171
October	Direct	459	650	797	889	920	889	798
	Diffuse	315	274	236	204	179	163	158
KT = 0.46	Reflected	0	20	39	55	67	75	77
	TOTAL	774	944	1072	1147	1166	1127	1033
November	Direct	211	357	479	569	619	628	594
	Diffuse	202	176	152	131	115	105	101
KT = 0.37	Reflected	0	11	21	29	36	40	41
	TOTAL	413	544	652	729	770	772	736
December	Direct	108	204	286	348	387	399	384
	Diffuse	157	137	118	102	89	81	79
KT = 0.30	Reflected	0	7	13	19	23	26	27
	TOTAL	265	348	417	468	499	506	489
AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY) ASTORIA, OREGON								
DEC-JAN		293	380	452	505	536	541	521
NOV-MARCH		521	637	727	783	803	785	730
OCT-APRIL		684	801	883	926	927	885	803
ALL YEAR		1115	1191	1221	1200	1130	1016	867

Prosser, WA 46°15'

5-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	263	466	637	766	841	860	820
	Diffuse	187	163	140	121	106	97	94
	Reflected	0	12	22	32	39	43	45
	TOTAL	450	640	800	918	986	1000	958
	KT = 0.45							
February	Direct	572	858	1085	1239	1307	1287	1179
	Diffuse	268	233	201	173	152	139	134
	Reflected	0	22	42	59	73	81	84
	TOTAL	841	1113	1328	1471	1532	1507	1397
	KT = 0.56							
March	Direct	896	1141	1309	1387	1371	1261	1066
	Diffuse	387	337	290	250	219	200	193
	Reflected	0	33	64	91	111	124	128
	TOTAL	1283	1512	1663	1728	1702	1585	1388
	KT = 0.58							
April	Direct	1436	1599	1658	1608	1451	1200	871
	Diffuse	481	419	361	311	273	249	240
	Reflected	0	50	96	136	166	185	192
	TOTAL	1917	2067	2115	2054	1890	1634	1303
	KT = 0.65							
May	Direct	1691	1731	1674	1516	1268	947	581
	Diffuse	573	499	429	370	325	296	286
	Reflected	0	59	113	160	196	219	226
	TOTAL	2264	2288	2216	2047	1789	1462	1093
	KT = 0.64							
June	Direct	1994	1967	1842	1615	1298	915	503
	Diffuse	576	501	432	372	326	298	288
	Reflected	0	67	128	182	223	248	257
	TOTAL	2570	2535	2402	2168	1847	1461	1048
	KT = 0.68							
July	Direct	2134	2141	2035	1811	1483	1075	624
	Diffuse	499	434	374	322	283	258	249
	Reflected	0	68	132	186	228	254	263
	TOTAL	2633	2643	2540	2320	1994	1588	1136
	KT = 0.72							

Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1706	1835	1850	1746	1531	1219	834
	Diffuse	477	415	357	308	270	246	238
	Reflected	0	56	109	154	189	211	218
	TOTAL	2183	2306	2316	2209	1990	1676	1291
	KT = 0.69							
September	Direct	1380	1670	1847	1898	1819	1617	1305
	Diffuse	349	304	262	226	198	181	175
	Reflected	0	45	86	122	150	167	173
	TOTAL	1729	2019	2195	2246	2167	1965	1652
	KT = 0.71							
October	Direct	724	1027	1259	1405	1456	1408	1263
	Diffuse	293	255	220	190	166	152	147
	Reflected	0	26	51	72	88	98	102
	TOTAL	1018	1308	1530	1667	1711	1658	1512
	KT = 0.60							
November	Direct	324	550	739	878	957	970	918
	Diffuse	207	180	155	134	117	107	104
	Reflected	0	14	27	38	46	51	53
	TOTAL	531	744	921	1049	1120	1128	1074
	KT = 0.48							
December	Direct	212	400	561	683	760	784	755
	Diffuse	161	140	121	104	91	83	80
	Reflected	0	10	19	26	32	36	37
	TOTAL	372	549	700	814	883	903	873
	KT = 0.43							
AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)								
PROSSER, WASHINGTON								
DEC-JAN		411	595	750	866	935	952	915
NOV-MARCH		694	909	1079	1192	1240	1220	1133
OCT-APRIL		914	1131	1291	1383	1404	1342	1213
ALL YEAR		1486	1646	1729	1725	1634	1463	1225

Corvallis, OR 44°38'

8 -Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	174	298	401	477	521	529	501
	Diffuse	198	173	149	128	112	103	99
KT = 0.34	Reflected	0	10	19	26	32	36	37
	TOTAL	372	480	569	632	666	667	637
February	Direct	242	355	443	501	525	514	467
	Diffuse	285	248	214	184	162	148	143
KT = 0.33	Reflected	0	14	26	37	46	51	53
	TOTAL	527	617	683	723	733	712	662
March	Direct	460	578	657	691	678	618	517
	Diffuse	414	360	310	268	235	214	207
KT = 0.39	Reflected	0	23	44	62	76	84	87
	TOTAL	874	961	1011	1020	988	917	811
April	Direct	679	750	772	743	665	544	388
	Diffuse	552	481	414	357	313	285	276
KT = 0.41	Reflected	0	32	62	87	107	119	123
	TOTAL	1231	1263	1248	1187	1085	948	787
May	Direct	1078	1097	1053	947	784	576	342
	Diffuse	663	577	497	428	376	343	331
KT = 0.49	Reflected	0	45	87	123	151	168	174
	TOTAL	1740	1718	1637	1498	1310	1087	848
June	Direct	1249	1226	1140	991	788	545	287
	Diffuse	698	608	524	451	396	361	349
KT = 0.52	Reflected	0	50	97	138	169	188	195
	TOTAL	1947	1884	1761	1580	1352	1094	831
July	Direct	1477	1474	1392	1229	996	710	397
	Diffuse	643	560	482	416	365	333	322
KT = 0.58	Reflected	0	55	106	150	184	205	212
	TOTAL	2120	2089	1980	1795	1544	1247	930

Reflectivity from ground, roof assumed at 20%

		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1161	1240	1241	1163	1011	794	532
	Diffuse	579	504	435	375	329	300	290
KT = 0.55	Reflected	0	45	87	123	151	168	174
	TOTAL	1740	1789	1763	1661	1490	1262	995
September	Direct	886	1061	1163	1186	1128	994	792
	Diffuse	456	397	342	295	258	236	228
KT = 0.54	Reflected	0	35	67	95	116	130	134
	TOTAL	1342	1492	1572	1576	1503	1359	1154
October	Direct	450	626	759	840	864	829	738
	Diffuse	328	285	246	212	186	170	164
KT = 0.44	Reflected	0	20	39	55	67	75	78
	TOTAL	778	931	1044	1107	1118	1074	980
November	Direct	168	277	367	432	467	471	442
	Diffuse	215	187	161	139	122	111	108
KT = 0.32	Reflected	0	10	19	27	33	37	38
	TOTAL	383	474	547	598	622	619	588
December	Direct	85	154	213	257	284	291	278
	Diffuse	169	147	127	109	96	88	85
KT = 0.27	Reflected	0	7	13	18	22	25	25
	TOTAL	254	308	353	384	402	403	388

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
CORVALLIS, OREGON

DEC-JAN	313	394	461	508	534	535	513
NOV-MARCH	482	568	632	671	681	663	617
OCT-APRIL	631	719	779	808	802	763	694
ALL YEAR	1113	1171	1184	1149	1070	951	802

A solar greenhouse is only one way to effectively use renewable energy in your home. Conservation is always the first and most important step. Once you have insulated, weatherstripped and caulked windows, and have made your existing heating system efficient, it may be time to investigate solar for heating your home and domestic hot water. This illustration shows a solar water heater installed in a south-facing greenhouse attached to a residence, much like the passive solar home built by Jo nad George Yount in Edmonds, Washington.

We at Ecotope Group believe that attached south-facing greenhouses and domestic water heating are effective ways to use solar energy in the Northwest. If you are interested in possible do-it-yourself solar water heating, a good resource is Ecotope's publication, A SOLAR WATER HEATER WORKSHOP MANUAL. The SOLAR WATER HEATER MANUAL, like the SOLAR GREENHOUSE GUIDE, is available from Ecotope Group or at quality Northwest book shops for \$5.

Please write us for our publications list and for information on discounts for bulk purchases of GUIDES and MANUALS used for workshops you are sponsoring.

